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(54) A low nitrogen oxide producing combustion method and apparatus

(57) Apparatus for and a method of achieving combustion with a low production of nitrogen oxide, in a burner having an air pipe (2) the delivery opening of which is closed by a baffle plate (4) with a plurality of slot-like air delivery openings (3) around a fuel pipe (1) at or adjacent the tip of the fuel pipe, main fuel injectors (5) having radially directed fuel (6) adjacent the air delivery openings (3), in which the tip of the fuel pipe (1) protrudes beyond the baffle plate (4) and has auxiliary fuel injection holes (16; 16'; 17). In operation fuel is injected from the main fuel injection pipes (5) transversely into the air stream just before it is delivered from the air delivery openings (3); 10 to 20% of the total fuel is injected as auxiliary fuel from the auxiliary fuel injection holes (16; 16'; 17) so as to entrain the furnace combustion product gas for combustion; and the ratio of the air flow velocity at the air delivery openings (3) to the fuel flow velocity at the main fuel injectors (5) is 0.2 or more.

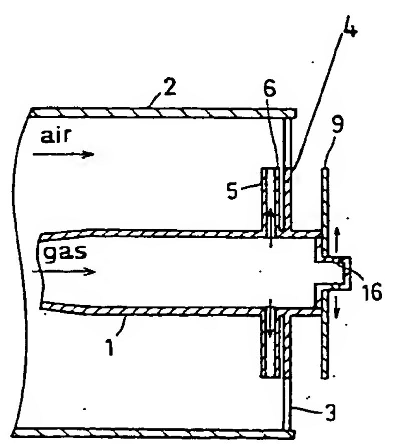

FIG 1A

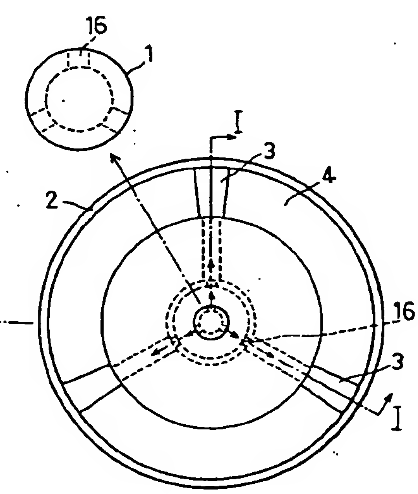

FIG 1B

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Description

The regulations against the emission of NOx caused by combustion are intensified year after year, and much technical activity is directed at decreasing NOx emissions. NOx generated by combustion includes fuel NOx, prompt NOx and thermal NOx. Among these types of NOx, thermal NOx is produced when the nitrogen molecules in combustion air are oxidised in a high temperature atmosphere, and this is highly temperature dependent. NOx production increases sharply at higher combustion temperatures. Thermal NOx is inevitably produced if the combustion gas, that is the gas in the presence of which combustion takes place, contains nitrogen molecules. When a hydrocarbon-based fuel is burned, the NOx emitted is mostly thermal NOx. A number of methods for decreasing NOx has been proposed, including multi-stage combustion methods, exhaust gas recirculation methods, and lean combustion methods.

In multi-stage combustion methods, the fuel or the combustion air is divided for combustion into two or more stages, and low NOx combustion is sought by keeping the flame temperature low or by keeping the oxygen concentration low. These combustion methods have a problem in that multi-stage combustion makes the burner complicated. Exhaust gas recirculation methods are intended to lower the flame temperature or to lower the oxygen concentration by mixing part of the combustion product gas with combustion air or fuel, and include forced exhaust gas recirculation methods and self-induced exhaust gas recirculation methods. The forced exhaust gas recirculation methods use a recirculation duct and a blower to mix part of the combustion product (or exhaust) gas forcibly with combustion air or fuel, and these are the most general methods.

In self-induced exhaust gas recirculation methods, a specially devised burner is used in which combustion air flow or fuel flow entrains the combustion product gas to achieve the effect of exhaust gas recirculation by jet entrainment. Self-induced exhaust gas recirculation methods have an advantage in that the effect of exhaust gas recirculation can be obtained without forcibly recirculating the combustion product gas, and is free from the complications of multi-stage combustion methods in which the fuel or the combustion air is divided into a plurality of lines. A burner which operates with self-induced exhaust gas recirculation is disclosed, for example, in Japanese Laid-Open Patent No. 87-17506. There are other burners which use the self-induced exhaust gas recirculation method. However, the ability of these methods to decrease NOx is limited and further technical development is necessary to meet the latest severe NOx regulations.

Combustion methods developed to maximise the advantage of self-induced exhaust gas recirculation are proposed in Japanese Laid-Open Patent No. 89-300103 and 91-91601, and Japanese Laid-Open Utility Model No. 77-61545. These combustion methods are characterised in that combustion air and fuel are separately and independently injected into a furnace having a burner devoid of any flame stabilising mechanism, to maximise the effect of the self-induced exhaust gas recirculation. In this configuration, the flame is not stabilised at the burner, but is formed at a raised position, and combustion begins after part of the combustion product gas in the furnace has been entrained by either the fuel or the combustion air. In these combustion methods, the flame is a gentle diffusion flame. Since there is no flame stabilising mechanism, it can happen that unless the furnace temperature is high, stable ignition cannot be achieved. Thus, although these methods are suitable for high temperature furnaces such as heating furnaces and melting furnaces, they have problems when they are applied to boilers and lower temperature heating furnaces in that the amount of unburned fuel increases and a larger furnace must be used for complete combustion.

Another method for reducing thermal NOx is to use a premixed flame. Premixed combustion at a high excess air ratio can significantly decrease NOx, but a high excess air ratio is likely to decrease combustion efficiency and the efficiency of heat transfer. Furthermore, the flame in a premixed combustion system has a poor stability with obvious disadvantages.

A method of decreasing thermal NOx by combining premixed combustion with self-induced exhaust gas recirculation is proposed in Japanese Laid-Open Patent No. 91-175211. In this combustion method the flame stabiliser is specially devised, and in order to lower the flame temperature, or to lower the oxygen concentration, so as the decrease NOx, part of combustion product gas is mixed at relatively low temperature with the premixture before the premixture initiates combustion. This combustion method and the apparatus for performing it also suffer from the disadvantages of other premixed type burners in that, since part of the combustion product gas is mixed with an inflammable premixture, ignition may well occur immediately after mixing of the premixture and the combustion product gas if the latter is at a high temperature, and this prevents the full effect of the self-induced exhaust gas recirculation to be sufficiently used. The flame stabiliser must therefore be specifically devised to ensure that the premixture is not ignited when the premixture and part of combustion product gas are mixed.

As described above, self-induced exhaust gas recirculation methods have advantages compared with other low NOx combustion methods such as multi-stage combustion methods and diluted premixed combustion methods in that even with a simple burner low NOx combustion is possible. In combustion methods for decreasing thermal NOx by using self-induced exhaust gas recirculation, if self-induced exhaust gas recirculation is used to the maximum extent for the diffusion flame, the temperature range usable in the furnace is limited, and the usable combustion equipment is also limited. This is a disadvantage. Moreover, the applica-

tion of self-induced exhaust gas recirculation to burners using pre-mixed fuel and air has problems of flame stability peculiar to the premixed combustion, such as combustion blow back, and suffers the disadvantages that it requires a more specifically devised flame stabiliser.

To achieve lower NOx combustion in response to the increasingly intensified NOx regulations for burners, a combustion technique for more effectively using self-induced exhaust gas recirculation is desired. The present invention has paid attention to this point. The present invention seeks to provide a low-nitrogen-oxide-producing combustion method and apparatus, in which effective self-induced exhaust gas recirculation can occur before the initiation of combustion by the formation of diffusion flames, or in which part of the combustion product gas may be entrained by a stream of auxiliary fuel or by the combustion air or by the main fuel flow before the formation of diffusion flames, whereby to intensify the recirculation flow of the combustion product gases. In addition, combined rich and lean combustion in the diffusion flames may be achieved, for decreasing the generation of NOx by a combination of these measures. Embodiments of the invention are excellent in flame stability even in a low temperature atmosphere.

According to one aspect of the present invention, there is provided a method of achieving combustion with a low production of nitrogen oxide, characterised in that it uses a burner having an air delivery pipe with a baffle plate having a plurality of air delivery openings around a fuel pipe at or adjacent the tip of the fuel pipe, main fuel injectors connecting to the said fuel pipe and having fuel outlets in the vicinity of the said plurality of air delivery openings, in which the tip of the fuel pipe protrudes beyond the baffle plate and has auxiliary fuel injection holes therein, in which fuel is injected from the said main fuel injectors in a direction transverse that of the air stream just before the air stream is delivered from the said plurality of air delivery openings; in which 10 to 20% of the total fuel is injected as auxiliary fuel from the auxiliary fuel injection holes so as to entrain the furnace combustion product gas for combustion; and in which the ratio of the air flow velocity at the said air delivery openings to the fuel flow velocity at the main fuel injectors is 0.2 or more.

According to another aspect of the invention there is provided a low-nitrogen-oxide-producing combustion apparatus, comprising an air pipe having a baffle plate with a plurality of air delivery openings around a fuel pipe at or adjacent the tip of the fuel pipe, main fuel injection pipes connecting to the said fuel pipe in the vicinity of the said plurality of air delivery openings and having main fuel injecting openings for injecting fuel radially into the air pipe, the tip of the fuel pipe protruding beyond the baffle plate, auxiliary fuel injection holes for injecting auxiliary fuel being formed at the tip of the fuel pipe, and a disc larger in diameter than the fuel pipe, being installed upstream of the auxiliary fuel injection holes.

Various embodiments of the invention will now be more particularly described by way of example, with reference to the accompanying drawings, in which:

Figure 1A is an axial sectional illustration taken on the line I-I of Figure 1B showing a first embodiment of the present invention;

Figure 1B is an end view of the embodiment illustrated in Figure 1A;

Figures 2A and 2B are respectively a sectional illustration on the line II-II of Figure 2B, and an end view, of a second embodiment of the invention;

Figures 3A and 3B are respectively an axial section on the line III-III of Figure 3B, and an end view, of a third embodiment of the invention;

Figures 4A and 4B are respectively an axial section on the line IV-IV of Figure 4B, and an end view, of a further embodiment of the invention;

Figures 5A and 5B are respectively an axial section on the line V-V of Figure 5B, and an end view, of a further embodiment of the invention;

Figure 6 is an axial sectional view showing the embodiment of Figures 1A and 1B in operation;

Figure 7 is an axial sectional view of the embodiment of Figures 5A and 5B in operation, showing the paths of fluids through the burner;

Figure 8 is a schematic view showing the way the fuel circulates after leaving the outlet end of a fuel pipe;

Figure 9 is a schematic view showing the way the fuel is entrained by the air stream in the embodiments of Figures 1 to 5;

Figure 10 is a diagram showing typical NOx emission performance of the embodiments of Figures 1 to 7;

Figure 11 is a diagram showing how the NOx emission performance of the embodiments of Figures 1 to 7 varies with variation of auxiliary fuel injection;

Figure 12 is a diagram comparing the NOx emission performance of the embodiments of Figures 1 to 7 with that of conventional burners;

Figures 13A and 13B are respectively an axial section on the line XIII-XIII of Figure 13B, and an end view, of an alternative embodiments of the invention;

Figures 14A and 14B are respectively an axial section on the line XIV-XIV of Figure 14B, and an end view, of a second alternative embodiment;

Figures 15A and 15B are respectively an axial section on the line XV-XV of Figure 15B, and an end view, of a third alternative embodiment of the invention;

Figures 16A and 16B are respectively an axial sectional view taken on the line XVI-XVI of Figure 16B, and an end view, of a fourth alternative embodiment of the invention;

Figures 17A and 17B are respectively an axial sectional view taken on the line XVII-XVII of Figure

17B, and an end view, of a fifth alternative embodiment of the invention;

Figures 18A and 18B are respectively an axial sectional view taken on the line XVIII-XVIII of Figure 18B, and an end view, of a sixth alternative embodiment of the invention;

Figure 19 is an axial sectional view showing the typical path of fluids through the burner nozzle and the entrainments effected thereby in the embodiments of Figures 13 to 18;

Figure 20 is an axial sectional view through a typical embodiment of Figures 13 to 18 showing the flow of fluids through the burner nozzle and the entrainments effected thereby;

Figure 21 is a schematic representation of the NOx performance and the variation in performance caused by variation of the cross-sectional area of the annular air stream in relation to the overall cross-sectional area of the air introduction openings, with a comparison being made with the performance of a conventional burner;

Figure 22 is a diagram comparing the performance of embodiments of the present invention at critical upper and lower limits of the ratio of CO to excess air in embodiments in which there is an opening delivering an annular air stream, blotting the comparative performance with embodiments in which no annular air stream-forming opening is provided;

Figures 23A and 23B are respectively an axial sectional view taken on the line XXIII-XXIII of Figure 23B, and an end view, of a further embodiment of the invention;

Figures 24A and 24B are respectively an axial sectional view taken on the line XXIIII-XXIIII of Figure 24B, and an end view, of still another embodiment of the invention;

Figures 25A and 25B are respectively an axial sectional view taken on the line XXV-XXV of Figure 25B, and an end view, of yet a further embodiment of the invention;

Figures 26A and 26B are respectively an axial sectional view taken on the line XXIV-XXIV of Figure 26B, and an end view, of another embodiment of the invention;

Figures 27A and 27B are respectively an axial sectional view taken on the line XXVII-XXVII of Figure 27B, and an end view, of yet another embodiment of the invention, with a broken line alternative configuration illustrated for one of the components;

Figures 28A and 28B are respectively an axial sectional view taken on the line XXVIII-XXIII of Figure 28B, and an end view, of still a further embodiment of the present invention with a broken line insert showing an alternative configuration for one of the components;

Figures 29A and 29B are respectively an axial sectional view taken on the line XXIX-XXIX of Figure 29B, and an end view, of yet another further embodiment of the invention, with various broken line and solid line inserts showing certain components on a larger scale;

Figures 30A and 30B are respectively an axial sectional view taken on the line XXX-XXX of Figure 30B, and an end view, of still another further embodiment of the invention with a number of broken line and solid line detail inserts showing the configuration of various components on a larger scale;

Figures 31A and 31B are respectively an axial sectional view taken on the line XXXI-XXXI of Figure 31B, and an end view, of still yet another embodiment of the invention with various components shown on a larger scale and with broken and solid outlines;

Figures 32A and 32B are respectively an axial sectional view taken on the line XXXII-XXXII of Figure 32B, and an end view, showing various different components on an enlarged scale and in broken line and solid line inserts;

Figures 33A and 33B are respectively an axial sectional view taken on the line XXXIII-XXXIII of Figure 33B, and an end view, with a number of inserts on an enlarged scale showing details of the structure, and a further broken line insert showing an alternative configuration for one of the components;

Figures 34A and 34B are respectively an axial sectional view taken on the line XXXIV-XXXIV of Figure 34B, and an end view, of still a further embodiment of the invention with a number of broken line inserts on a larger scale and a broken line alternative configuration for one of the components;

Figure 35 is a diagram showing the performance of a burner of the present invention in comparison with a conventional burner using the embodiments of Figures 23 to 34; and

Figure 36 is a diagram comparing the performance of embodiments of the present invention illustrated in Figures 23 to 34 in comparison with a conventional burner to illustrate the decrease in NOx production at different overall air ratios.

Referring now to the drawings, there is shown a burner adapted whereby greatly to decrease the NOx produced during combustion by delivering air flow from slot-like air injecting openings, and by injection of part of the fuel, as auxiliary fuel, so that diffusion flames may be formed with the fuel wrapped by air, and burned without being stabilised either at the air delivery opening or the fuel injecting outlets to ensure that part of the combustion product gas may be entrained by the auxiliary fuel flow as well as by the air and fuel flow before the diffusion flames are formed, whereby very effectively to achieve self-induced exhaust gas recirculation.

In Figure, symbol 1 denotes a fuel pipe, and close to the tip of the fuel pipe there is a baffle plate 4 with a plurality of slot-like air delivery openings 3. This baffle surrounds the fuel pipe and lies in contact with the inside surface of an air pipe 2 which coaxially surrounds

the fuel pipe 1. Closely adjacent the plurality of slot-like delivery openings 3, are radially extending main fuel injector pipes 5 connecting with the fuel pipe 1 and having main fuel injection openings 6 at their radially outer ends for injecting the fuel in a radial direction.

At the very tip of the fuel pipe 1 there are radial fuel injector holes 16 for injecting auxiliary fuel in the same directions as the injection directions of the main fuel injector openings 6 at the ends of the main fuel injector pipes 5. Between the auxiliary injector holes 16 and the baffle 4 there is a disc 9 larger in diameter than the fuel pipe and approximately the same diameter as the circumscribing circle on which lie the tips of the main fuel injector pipes 5.

In the embodiment of Figure 2, most of the components are the same as in the embodiment of Figure 1 and are identified with the same reference numerals. It differs in the provision of radial fuel injector holes 16' at the tip of the gas pipe 1 for injecting auxiliary fuel in radial directions into the spaces between air delivery openings downstream of those openings.

The embodiment of Figure 3 differs from the previous two embodiments in that radial fuel injection holes 16' for injecting the auxiliary fuel in radial directions between the slot-like air delivery openings 3, are provided in addition to radial fuel injection holes 16 for injecting the auxiliary fuel in the same directions as the injection direction of the main fuel injecting pipes 5.

In the embodiment of Figure 4, there are provided radial fuel injection holes 16' for injecting the auxiliary fuel radially between the slot-like air delivery openings 3 and axially directed fuel injection holes 17 for injecting auxiliary fuel in a direction parallel to the axis of the fuel pipe 1.

The embodiment of Figure 5 has radial fuel injection holes 16 for injecting auxiliary fuel in the same direction as the injection directions of the main fuel injector pipes 5 and axially directed fuel injector holes 17 for injecting auxiliary fuel in a direction parallel to the central axis of the fuel pipe 1.

As shown in the broken line insert to Figure 5 the axial fuel injection holes 17 may also have an annular guide hole 18. Symbol 21 denotes a swirl vane in the annular guide hole 18.

In the embodiments described above air is delivered through the slot-like air delivery openings 3, and fuel gas is injected into the air flow from the main fuel injector pipes 5 in a direction perpendicular to the air flow just before the air flow is delivered through the slot-like air delivery openings 3. In this case, the ratio of the air flow velocity at the slot-like air delivery openings 3 to the fuel gas flow velocity at the injector openings 6 of the main fuel injector pipes 5 must be set at 0.2 or more and in practice between about 0.2 and about 5. If the ratio is less than 0.2, the fuel gas can pass right through the air flow, to collide with the inside wall of the air pipe 2, it is thus diffused into the air and flames can form and be stabilised in the air pipe 2. If the ratio is set as specified above, diffusion flames stabilised at the slot-like air delivery openings 3 are not formed, but the fuel gas flow injected in a direction perpendicular to the air flow is wrapped in the air flow 12 as shown in Figures 6 and 7. In this case, radial auxiliary fuel injection flow 19 and as appropriate axial auxiliary fuel injection flow 20 are injected from the radial and/or axial auxiliary fuel injection holes 16, 16' and 17 as appropriate into the recirculation area 10 and toward the furnace combustion gas flow 13 and the internal recirculation area 14. The radial auxiliary fuel injection flow 19 and axial auxiliary fuel injection flow 20 each entrains a large amount of combustion product gas before combustion takes place whereby further to promote self-induced exhaust gas recirculation in the internal recirculation area 14, thereby further to decrease NOx.

With the fuel gas flow 11 in the centre of the stream, the air flow 12 is formed around it like a doughnut. The radial auxiliary fuel injection flow 18 and, as appropriate, the axial auxiliary fuel injection flow each entrain furnace gas 13 to form the recirculation flow in the recirculation area 14 as shown by arrows. Furnace gas 13 is entrained by the air flow 12 around the annular stream of gas and air. The high temperature furnace gas flow 13 is diffused and mixed from the outside, while simultaneously, the fuel gas flow 11 is diffused and mixed from inside.

In the case of diffusion flames, formed by prior art burners since the flames formed are stabilised at air injection holes or fuel gas injection holes, combustion begins before the air flow can entrain the surrounding furnace gas. However, in the present invention, since the flow velocity ratio is set as specified above, the flames are not stabilised at the slot-like air delivery openings 3 or the main fuel injecting openings 6. In the present invention, the air flow 12 is mixed with the furnace gas flow 13 while being heated, and at the same time, it is gradually mixed with the fuel gas flow 11 and with the radial auxiliary fuel injection flow 19 and, as appropriate, the axial auxiliary fuel injection flow 20. These four components develop a favourable mixed state, and when the temperature, fuel concentration and oxygen concentration satisfy the ignition conditions, combustion is initiated to form diffusion flames. In these diffusion flames, since part of the combustion product gas is mixed with the combustion air and the fuel flow, and/or the auxiliary fuel flow before the combustion is initiated, the effect of self-induced exhaust gas recirculation can be obtained to the maximum extent, and the resulting lower flame temperature and lower oxygen concentration ensure very low NOx production. In this case, the internal recirculation area 14 and the external recirculation area 15 contribute greatly for the entrainment of a large quantity of the furnace gas flow 13.

The baffle plate 4 around the fuel pipe 1 at the tip of the fuel pipe 1 in the air pipe 2 and in contact with the inside wall of the air pipe 2 has relatively large slot-like air delivery openings 3, through which combustion air is delivered. Therefore, the area of the air jets can be kept large, and the combustion product gas around the air

stream can be efficiently entrained. Furthermore, since a plurality of slot-like air delivery openings 3 are formed, the air flow 12 is delivered as separate streams or jets and the respective jets entrain the furnace gas flow 13. Thus, compared to a burner with one air jet, the combustion gas around the air flow can be efficiently entrained, to enhance the effect of self-induced exhaust gas recirculation. In the region surrounded by the plurality of combustion air jets, the internal recirculation area 14 is formed, and around the plurality of combustion air jets, the external recirculation area 15 is formed. In both the recirculation areas, part of the combustion product gas is recirculated and entrained by the combustion air jets. Especially in the internal recirculation area 14, high temperature combustion gas is recirculated, and hence the diffusion flames not stabilised at any openings can be ignited and formed stably.

By injecting the fuel in a direction perpendicular to the air flow and setting the ratio of the air flow velocity to the fuel flow velocity as specified above, the fuel jets can be reliably injected into the centres of the combustion air jets. In this case, as shown in Figures 8 and 9, each fuel jet forms twin eddies. The eddies grow according to the progression of mixing between the fuel and the air and according to the distance away from the main fuel injecting openings 6, and also from the slot-like air delivery openings 3. The eddies are mixed with the fuel and the air, and furthermore gradually entrain the part of the combustion product gas entrained by the air. If a large enough quantity of hot combustion product gas is entrained to ignite the fuel, the fuel initiates combustion. The eddies assure the stable ignition of flames even through the flames are not stabilised at the slot-like air delivery openings 3 or the main injecting openings 6. If the fuel is injected in a direction perpendicular to the air flow 12 destined to pass through the slot-like air delivery openings, with the ratio of the combustion air jet flow velocity to the fuel jet flow velocity kept at 0.2 or more, the flames can be formed without being stabilised at the injection holes, with very low NOx production as described before.

In the case of the embodiment of Figure 1, since the radial auxiliary fuel injection flow 19 injected from the radial fuel injection holes 16 is in the same directions as the injection directions of the main fuel injecting openings 6, the auxiliary fuel and the furnace gas are mixed before combustion, as described above, to promote self-induced exhaust gas recirculation, thereby further promoting the NOx decrease effect in synergism with the combustion.

In the case of the embodiment of Figure 3, since the auxiliary fuel is injected from the radial fuel injection holes 16' in radial directions into the spaces downstream of the areas between the adjacent slot-like air delivery openings 3 and simultaneously injected from the radial fuel injection holes 16 in the same directions as the injection directions of the main fuel injecting openings 6, the auxiliary fuel and the furnace gas are mixed before combustion as described before, to promote self-induced exhaust gas recirculation, thereby further promoting the NOx decrease effect in synergism with combustion.

In the case of Figure 4, the auxiliary fuel is injected not only from the radial fuel injection holes 16' in radial directions into the spaces downstream of the areas between adjacent slot-like air delivery openings 3 but also simultaneously from the axial fuel injection holes 17 in the axial direction of the fuel pipe 1, the auxiliary fuel and the furnace gas are mixed before combustion as described before, to promote self-induced exhaust gas recirculation, thereby further promoting the NOx decrease effect in synergism with combustion.

In the case of the embodiment of Figure 5, since auxiliary fuel is injected from the radial fuel injection holes 16 in the same directions as the injection directions of the main fuel injecting openings 6 while simultaneously being injected from the axial fuel injection holes 17 in the axial direction of the fuel pipe 1, the auxiliary fuel and the furnace gas are mixed before combustion as described before, to promote the self-induced exhaust gas recirculation, thereby further promoting the NOx decrease effect in synergism with said combustion.

If the central axial fuel injection hole 17 is formed with or as an annular guide hole 18, the auxiliary fuel stream is annular and this increase the contact area with the furnace gas, for considerably improving the self-induced exhaust gas recirculation to promote the NOx decrease effect. Furthermore, if a swirl vane 21 is installed in the annular hole 18, the fuel is injected annularly in swirl, to increase the entrained furnace gas, for further improving the self-induced exhaust gas recirculation, thereby promoting the NOx decrease effect.

Figure 10 shows the NOx decrease effect of the present invention. From the diagram, it can be seen that if the air/fuel velocity ratio is 0.2 or more, NOx production is significantly decreased compared to conventional burners.

Figure 11 shows the NOx decrease effect of this invention. From Figure 11 and Figure 12 showing a comparison with the conventional burners, it can be seen that if the air/fuel flow velocity ratio is 0.2 or more and if 10 to 20% of the overall fuel is injected as auxiliary fuel, NOx production is decreased significantly.

Further embodiments of the invention are illustrated in Figures 13 to 21. In these embodiments NOx production is decreased by delivering a stream of air from slot-like air delivery openings and injecting fuel into the air stream in a direction perpendicular to the air stream just before the air flow stream is delivered from the slot-like air delivery openings, while also injecting auxiliary fuel, so that diffusion flames may be formed with the fuel wrapped by air, and burned without being stabilised at the air delivery openings or fuel injecting openings, so as to ensure that part of the combustion product gas may be entrained by the auxiliary fuel flow, the air flow and the fuel flow before the diffusion flames are formed, whereby very effectively to achieve self-induced exhaust gas recirculation; and furthermore by delivering

air from an air delivery opening so shaped as to form an annular air stream downstream of a baffle plate, so that a strong negative pressure region may be formed inside the annular air stream to increase the recirculation flow of the furnace combustion product gas, for further promotion of internal recirculation, thereby forming a strong ignition source by the recirculation of high temperature furnace gases, thus achieving excellent flame ignition and stable combustion, and effectively promoting self-induced exhaust gas recirculation combustion.

In Figures 13 and 14, symbol 1 denotes a fuel pipe installed in an air pipe 2. A baffle plate 4 provided with a plurality of slot-like air delivery openings 3 is installed around the fuel pipe 1 at the tip of the fuel pipe 1. Around the edge of the baffle plate 4, an air flow delivery opening 23 for forming an annular air stream is provided, and adjacent the plurality of slot-like air delivery openings 3, main fuel injection pipes 5 connecting to the fuel pipe 1 are installed. At the tips of the main fuel injection pipes are main fuel injecting openings 6 for injecting fuel gas radially into the streams. At the tip of the fuel pipe 1, radial fuel injection holes 16 for injecting auxiliary fuel gas in the same directions as the injection directions of the main fuel injecting openings 6 are provided, and a disc 9 larger in diameter than the fuel pipe 1 is provided upstream of the radial fuel injection holes 16. The air delivery opening 23 for forming an annular air stream can be formed as an annular slit 24 between the air pipe 2 and the baffle plate 4, or by an annular array of small holes 25 just inside the edge of the baffle plate 4. In Figures 15 to 18 only the annular slit 24 is shown for the sake of convenience but it will be appreciated that this may be replaced by an annular array of holes.

In the case of Figure 15, radial fuel injection holes 16' for injecting the auxiliary fuel in radial directions into the spaces downstream of the areas between the adjacent slot-like air delivery openings 3 are provided.

In the case of Figure 16 there are provided radial fuel injection holes 16' for injecting the auxiliary fuel in radial directions into the spaces downstream of the areas between adjacent slot-like air delivery openings 3, as well as radial fuel injection holes 16 for injecting the auxiliary fuel in the same directions as the injection directions of the main fuel injecting openings 6.

In the case of Figure 17 there are provided radial fuel injection holes 16' for injecting the auxiliary fuel in radial directions into the spaces downstream of the areas between adjacent slot-like air delivery openings 3 as well as axial fuel injection holes 17 for injecting the auxiliary fuel in the axial direction of the fuel pipe 1.

In the case of Figure 18 there are provided radial fuel injection holes 16 for injecting the auxiliary fuel in the same directions as the injection directions of the main fuel injecting openings 6 as well as axial fuel injection holes 17 for injecting the auxiliary fuel in the axial direction of the fuel pipe 1.

The axial fuel injection holes 17 may also be formed with an annular guide hole 18 shown in the broken line insert. Symbol 21 denotes a swirl vane in the annular guide hole 18.

In the above-described configurations, the air delivered through the air delivery opening 23 forms an annular air stream 26 downstream of the baffle plate 4 as shown in Figures 19 and 20, and a strong negative pressure region is formed inside the annular air stream 26, to increase the recirculation flow of furnace gases, thereby further promoting the self-induced exhaust gas recirculation in the internal recirculation area 14. The internal recirculation allows a powerful ignition source to be formed by the recirculation of the furnace gas at high temperature, to achieve excellent flame ignition and stable combustion, and effectively to promote self-induced exhaust gas recirculation combustion, thereby promoting the NOx decrease effect. Irrespective of whether the air delivery opening 23 for forming an annular air stream is formed as the annular slit 24 or by an array of small holes 25, the same phenomena and effect can be brought about. If the area of the air delivery opening 23 for forming an annular air stream is 20% or less of the overall air introducing area, the phenomena and effect can be promoted (see Figure 21).

In the above-described embodiment, the air delivery opening 23 for forming an annular air stream greatly contributes to the expansion of the combustion range. Figure 22 shows the upper and lower limits of critical CO excess air ratio measured with and without the air delivery opening 23. From Figure 22, it can be clearly seen that the air delivery opening 23 for forming an annular air stream greatly increases the critical CO upper limit excess air ratio.

Further embodiments of the present invention will now be described. These also act to decrease NOx production during combustion by injecting air from slot-like air delivery openings, and injecting fuel into the air stream in directions perpendicular to the air stream just before the air stream is delivered from the slot-like air delivery openings, while also injecting auxiliary fuel so that diffusion flames may be formed with the fuel wrapped by air, and burned without being stabilised at the air delivery openings or the fuel injecting openings so as to ensure that part of the combustion product gas may be entrained by the auxiliary fuel flow, the air flow and the main fuel flow before the diffusion flames are formed so as to achieve self-induced exhaust gas recirculation. By forming the diffusion flames at various excess air ratios, to achieve effective rich and lean flames and by delivering air from an air delivery opening shaped to form an annular air stream downstream of a baffle plate, so that a strong negative pressure region may be formed inside the annular air stream, the recirculation flow of the furnace combustion product gases increased and a strong ignition source is formed due to recirculation of high temperature furnace combustion product gases giving excellent flame ignition and stable combustion, and effectively promoting self-induced exhaust gas recirculation combustion.

In Figures 23 and 24, and Figures 29 and 30, symbol 1 denotes a fuel pipe coaxially within an air pipe 2. A baffle plate 4 having a plurality of slot-like air delivery opening 3 is installed around the fuel pipe 1 at the tip of the fuel pipe. Around or just inside the edge of the baffle plate 4 is an air delivery opening 23 shaped to form an annular air stream and at the radially inner ends of the plurality of slot-like air delivery openings 3 are main pipes 5 connecting to the fuel pipe 1. The plurality of slot-like air delivery openings 3 comprise two rich flame-forming delivery openings 27 and a lean-flame-forming air delivery opening 28.

At the tips of the main fuel injection pipes 5, main fuel injecting openings 6 for injecting fuel in radial directions are provided. At the tip of the fuel pipe 1 there are radial fuel injection holes 16 for injecting auxiliary fuel in the same directions as the injection directions of the main fuel injecting openings 6, and a disc 9 larger in diameter than the fuel pipe 1 is provided upstream of the radial fuel injection holes 16.

The air delivery opening 23 for forming an annular air stream can be formed as an annular slit 24 between the air pipe 2 and the baffle plate 4, or by an annular array of small holes 25 just inside the edge of the baffle plate 4. In Figures 25 to 30 the opening is shown as an annular slot, while in Figure 24 and annular array of small holes 25 is shown.

In the case of Figures 25 and 31, radial fuel injection holes 16' for injecting auxiliary fuel in radial directions into the spaces downstream of the areas between the adjacent slot-like air delivery openings 3 are provided.

In the case of Figures 26 and 32 there are radial fuel injection holes 16' for injecting auxiliary fuel in radial directions into the spaces downstream of the areas between adjacent slot-like air delivery openings 3, as well as radial fuel injection holes 16 for injecting auxiliary fuel in the same directions as the injection directions of the main fuel injecting openings 6.

In the case of Figures 27 and 33 there are radial fuel injection holes 16' for injecting the auxiliary fuel in radial directions into the spaces downstream of the areas between adjacent slot-like air delivery openings 3, as well as axial fuel injection holes 17 for injecting auxiliary fuel in the axial direction of the fuel pipe 1.

In the case of Figures 28 and 34 there are radial fuel injection holes 16 for injecting auxiliary fuel in the same directions as the injection directions of the main fuel injecting openings 6, and axial fuel injection holes 17 for injecting auxiliary fuel in the axial direction of the fuel pipe 1.

The axial fuel injection holes 17 may also be formed with an annular guide hole 18 as illustrated. Symbol 21 denotes a swirl vane installed in the annular hole 18.

In the case of Figures 23 to 28, the rich-flame-forming air delivery openings 27 and the lean-flame-forming delivery openings 28 have different areas. In the drawings, for example, one lean-flame-forming air delivery opening 28 and two rich-flame-forming air delivery opening 27 of smaller area are provided. The main fuel injection pipes 5 are all equal in diameter so that in this case, a lean flame with excessive air is formed downstream of the lean-flame-forming air delivery opening 28 and fuel-rich flames, that is flames with an excessive amount of fuel are formed downstream of the two rich-flame-forming air delivery openings 27 of smaller area.

In the case of Figures 29 to 34, the plurality of slot-like air delivery openings 3 are all equal in area, and the main fuel injecting openings 6 are different in area, to form two rich-flame-forming fuel injecting openings and one lean-flame-forming fuel injecting opening. Since the lean-flame-forming injecting opening 28 has a diameter d2 which is smaller than the diameter d1 of the other main fuel injecting openings 27a, a flame with excessive air is formed downstream of the lean-flame-forming fuel injecting opening 28, and fuel-rich flames that is flames with excessive fuel are formed downstream of the other rich-flame-forming fuel injecting openings 27.

It is also possible to make the slot-like air delivery openings 3 different in area from one another as well as the main fuel injecting opening 6 so that both the fuel and the air openings contribute to rich and lean combustion downstream of the rich-flame-forming injecting openings 27 and the lean-flame-forming injecting openings 28. That is, both the amount of air delivered and the amount of fuel injected can be different to set both the excess air ratios properly, for effectively achieving both rich and lean combustion from the same burner.

In this example, since the plurality of slot-like air delivery openings 3 are formed as the rich-flame-forming air delivery openings 27 and the lean-flame-forming air delivery opening 28, rich combustion and lean combustion progress concurrently. Downstream of the rich-flame-forming air delivery openings 27, rich flames with excessive fuel are formed, and downstream of the lean-flame-forming air delivery openings 27, a lean flame with excessive air is formed. The fuel-rich flames are lower in NOx emission than the stoichiometric combustion flame due to an insufficient oxygen concentration and the resultant drop of flame temperature, and the lean flame is also lower in NOx emission due to the drop of flame temperature. In this case, if both the excess air ratios are properly set so that the excessive air of the lean flame may be used to allow sufficient combustion of the excessive fuel in the rich flames, effective rich and lean combustion can be achieved. In this case, since the NOx emission level is the weighted mean of the fuel flow rates of both the rich flame and the lean flame, which are both lower in NOx emission level than a flame near the stoichiometric air ratio as described above, a low NOx emission level can be achieved for the whole combustion. Furthermore, in the present invention with an essential feature that the flames are not stabilized at any injecting opening, since the fuel and combustion air entrain the combustion gas before initiation of combustion, a lower NOx level can be more effectively achieved due to a lower oxygen concentration and a lower flame temperature. This rich and lean combustion can further

that through which combustion air for a lean flame is delivered.

12. A method, according to Claim 10 or Claim 11, characterised in that fuel for forming a rich flame is delivered through a main fuel injection pipe (5) having an outlet (6) of greater cross-sectional area than that of a main fuel injection pipe (5) through which fuel is delivered for forming a lean flame.

13. A method, according to any preceding claim, characterised in that oxygen enriched air of 21 vol% or more in oxygen concentration is used as the combustion air to be introduced into the air pipe.

14. A low-nitrogen-oxide-producing combustion apparatus, comprising an air pipe (2) having a baffle plate (4) with a plurality of air delivery openings (3) around a fuel pipe (1) at or adjacent the tip of the fuel pipe, main fuel injection pipes (5) connecting to the said fuel pipe (1) in the vicinity of the said plurality of air delivery openings (3) and having main fuel injecting openings (6) for injecting fuel radially into the air pipe (2), the tip of the fuel pipe protruding beyond the baffle plate (4), auxiliary fuel injection holes (16; 16'; 17) for injecting auxiliary fuel being formed at the tip of the fuel pipe, and a disc (9) larger in diameter than the fuel pipe, being installed upstream of the auxiliary fuel injection holes.

15. Apparatus according to Claim 14, characterised in that the auxiliary fuel injection holes (16) at the tip of the fuel pipe (1) are directed to inject auxiliary fuel in the same directions as the injection directions of the main fuel injectors (5) and/or in radial directions into the spaces downstream of the areas between adjacent air delivery openings (3).

16. Apparatus according to Claim 14 or Claim 15, characterised in that the auxiliary fuel injection holes (16; 16'; 17) at the tip of the fuel pipe include a hole (17; 18) directed for injecting auxiliary fuel in the axial direction of the fuel pipe (1).

17. Apparatus according to Claim 16, characterised in that the said axial fuel injection hole is formed as an annular opening (18) for injecting auxiliary fuel to form an annular stream from the axial fuel injection hole (18), whereby to entrain furnace combustion product gases.

18. Apparatus according to Claim 16, characterised in that a swirl vane (21) is located in the annular hole (18), for injecting auxiliary fuel from the annular hole (18) annularly in swirl.

19. Apparatus according to any one of Claims 14 to 18, characterised in that an air delivery opening (24) or openings (25) for forming an annular air stream is or are formed at or adjacent the edge of the baffle plate (4).

20. Apparatus according to Claim 19, characterised in that the air delivery opening (24; 25) for forming an annular air stream is formed by an annular slit (24) formed between the air pipe (2) and the baffle plate (4).

21. Apparatus according to Claim 19, characterised in that the air delivery opening (24; 25) for forming an annular air stream is formed by a circular array of holes (25) adjacent the edge of the baffle plate (4).

22. Apparatus according to any one of Claims 19, 20 or 21, characterised in that the area of the air delivery opening (24) or openings (25) for forming an annular air stream is 20% or less of the overall air delivery area.

23. Apparatus according to any preceding claim, characterised in that slot-like air delivery opening (3) are formed as rich-flame-forming air delivery openings and lean-flame-forming air delivery openings for achieving rich and lean combustion simultaneously.

24. Apparatus according to Claim 23, characterised in that the rich-flame-forming air delivery openings (3) and the lean-flame-forming air delivery openings (3) are formed as a plurality of openings of different area.

25. Apparatus according to Claim 23 or Claim 24, characterised in that the main fuel injection openings (6) of the main fuel injector pipes (5) have different cross-sectional areas, whereby to act as rich-flame-forming fuel injectors and lean-flame-forming fuel injectors respectively.

promote the decrease of NOx in synergism with the particular combustion described above.

Figure 35 shows the NOx decrease effect achieved by using the plurality of slot-like air delivery openings 3 of different sizes as the rich flame-forming air delivery openings 27 and the lean flame-forming air delivery openings 28. It can be understood that an air/fuel flow velocity ratio of 0.2 or more, the use of 10 to 20% of the overall fuel as the auxiliary fuel, the use of the air injecting portion 23 for forming an annular air stream with an area of 20% or less of the overall air introduction area, and the adoption of the above mentioned rich and lean combustion allows the NOx to be decreased significantly compared to the conventional burners.

Figure 36 shows the NOx decrease effect achieved by using the main fuel injecting openings 6 of different area as the rich flame-forming fuel injecting opening 27 and the lean flame-forming fuel injecting opening 28, using a plurality of slot-like air delivery openings 3 equal in size. It can be understood that an air/fuel flow velocity ratio of 0.2 or more, the use of 10 to 20% of the overall fuel as the auxiliary fuel, the use of the air delivery opening 23 for forming an annular air stream with an area of 20% or less of the overall air introduction area, and the adoption of the above mentioned rich and lean combustion allows the NOx to be decreased significantly as compared to the conventional burners and techniques.

If the combustion air introduced into the air pipe 2 is oxygen enriched air containing more than 21 vol% of oxygen, the combustion quantity can be increased, while the low NOx combustion is sustained.

Claims

1. A method of achieving combustion with a low production of nitrogen oxide, characterised in that it uses a burner having an air delivery pipe (2) with a baffle plate (4) having a plurality of air delivery openings (3) around a fuel pipe (1) at or adjacent the tip of the fuel pipe, main fuel injectors (5) connecting to the said fuel pipe (1) and having fuel outlets (6) in the vicinity of the said plurality of air delivery openings (3), in which the tip of the fuel pipe protrudes beyond the baffle plate (4) and has auxiliary fuel injection holes (16; 16'; 17) therein, in which fuel is injected from the said main fuel injection pipes (5) in a direction transverse that of the air stream just before the air stream is delivered from the said plurality of air delivery openings (3); in which 10 to 20% of the total fuel is injected as auxiliary fuel from the auxiliary fuel injection holes (16; 16'; 17) so as to entrain the furnace combustion product gas for combustion; and in which the ratio of the air flow velocity at the said air delivery openings (3) to the fuel flow velocity at the main fuel injectors (5) is 0.2 or more.

2. A method, according to Claim 1, characterised in that auxiliary fuel is injected radially into spaces downstream of the baffle plate (4) through radial fuel injection holes (16) in the tip of the fuel pipe directed to inject auxiliary fuel in the same directions as the injection directions of the main fuel injectors (5) and/or in radial directions into the spaces downstream of the areas between adjacent air delivery openings (3).

3. A method, according to Claim 1 or Claim 2, characterised in that auxiliary fuel is injected in the axial direction of the fuel pipe (1) through an axial fuel injection hole (17) in the tip of the fuel pipe (1).

4. A method, according to Claim 3, characterised in that furnace combustion product gases are entrained by an annular stream of fuel from an axial fuel injection hole (18) formed as an annular opening in the tip of the fuel pipe for injecting the auxiliary fuel to form the said annular stream of fuel.

5. A method, according to Claim 4, characterised in that the combustion product gas in the furnace is entrained by an annular stream of fuel caused to swirl by a swirl vane (21) located in the annular hole (18).

6. A method, according to any of Claims 1 to 5, characterised in that an annular air stream is formed by air passing through an air delivery opening (24; 25) formed at or adjacent the edge of the baffle plate (4).

7. A method, according to Claim 6, characterised in that air is delivered through an annular slit (24) formed between the air pipe (2) and the baffle plate (4).

8. A method, according to Claim 6, characterised in that air is delivered through an annular array of holes (25) thereby forming an annular air stream adjacent the edge of the baffle plate (4).

9. A method, according to any of Claims 6, 7 or 8, characterised in that an annular air stream of 20% or less of the overall air delivery is delivered through the said annular air delivery opening (24; 25) forming an annular stream.

10. A method, according to any preceding claim, characterised in that rich and lean combustion is achieved simultaneously by varying the ratio of fuel and air at different parts of the burner.

11. A method, according to Claim 10, characterised in that combustion air for forming a rich flame is delivered through a smaller air delivery opening (3) than

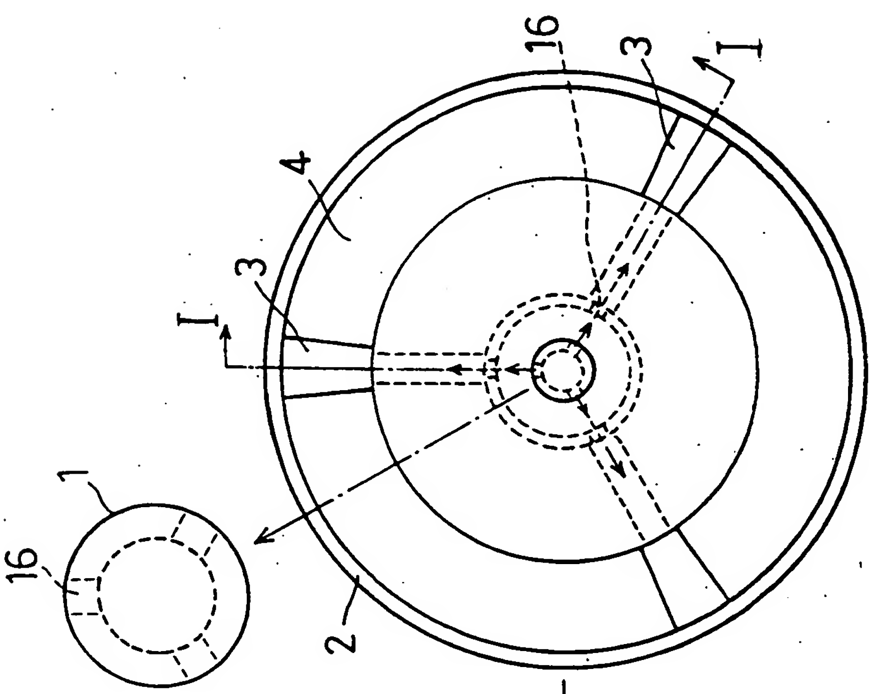


FIG 1B

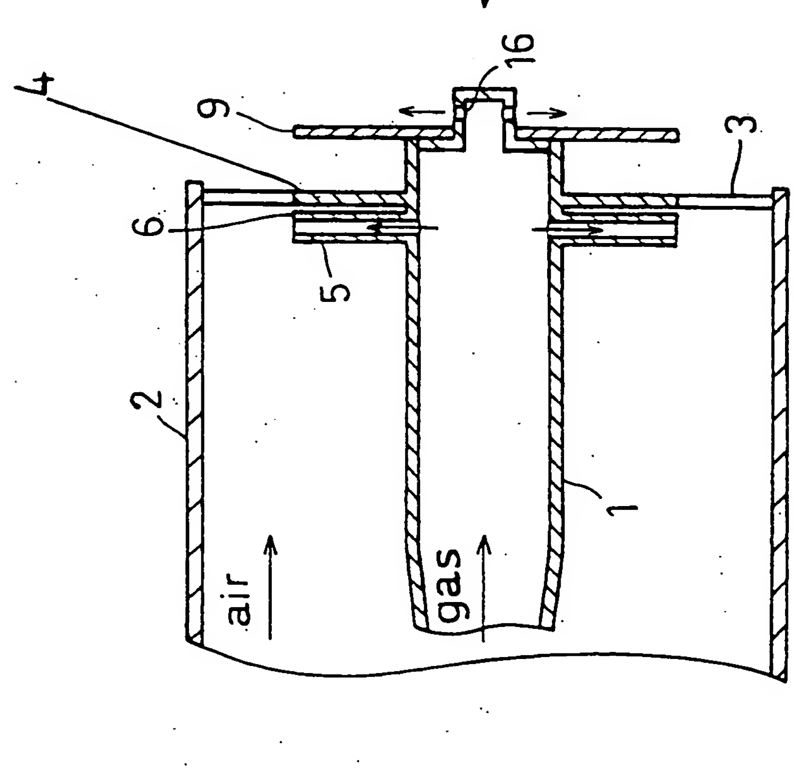


FIG 1A

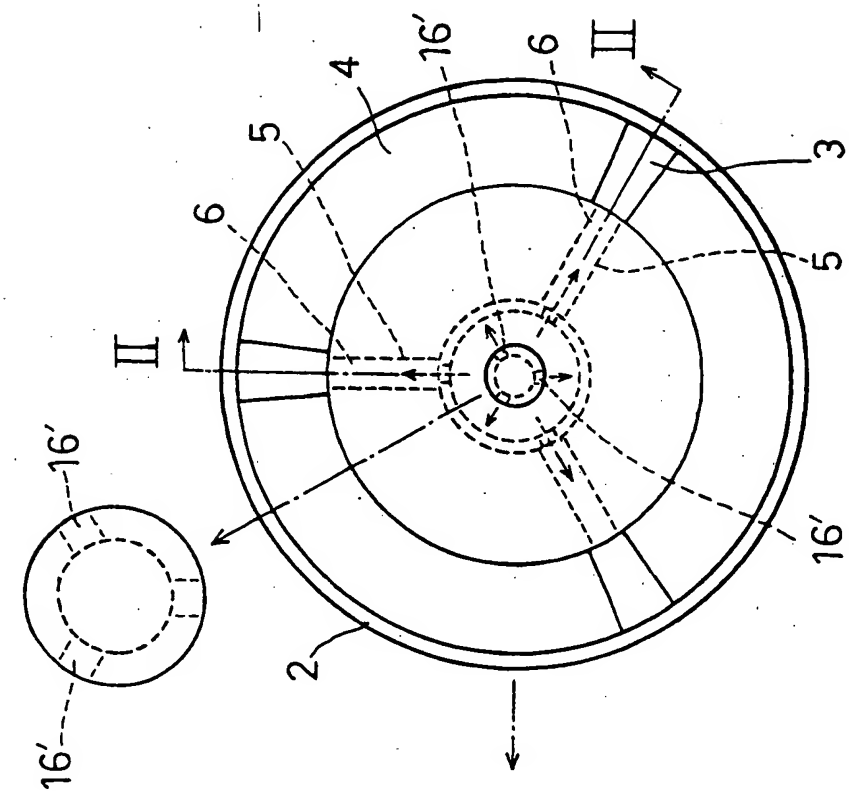


FIG 2B

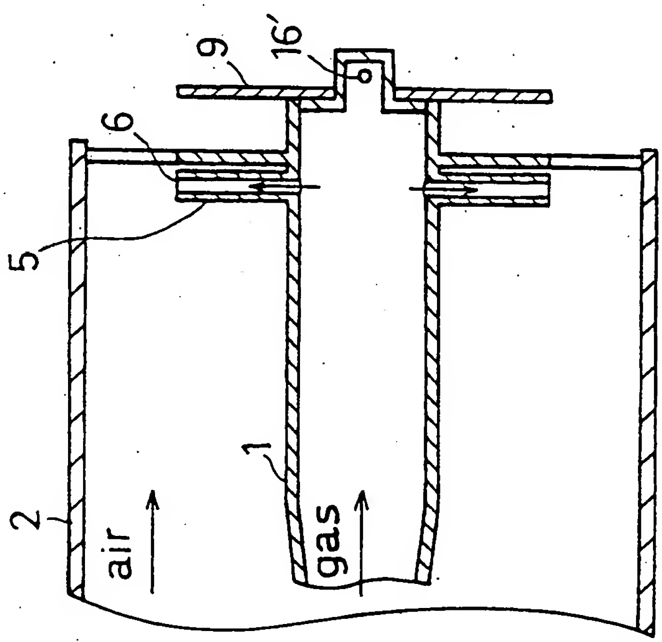


FIG 2A

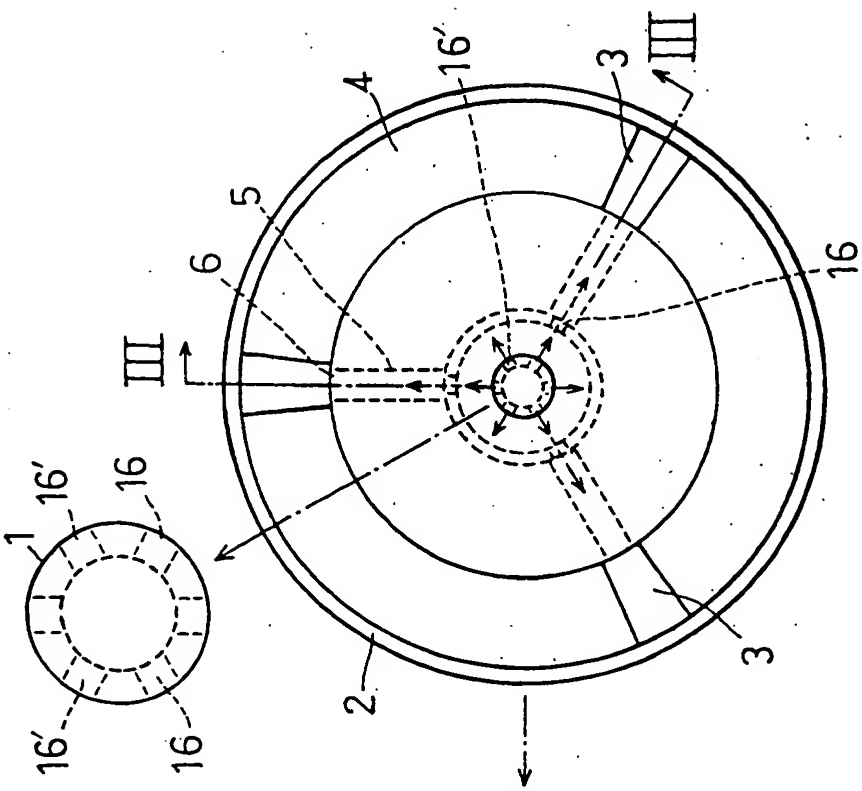


FIG 3B

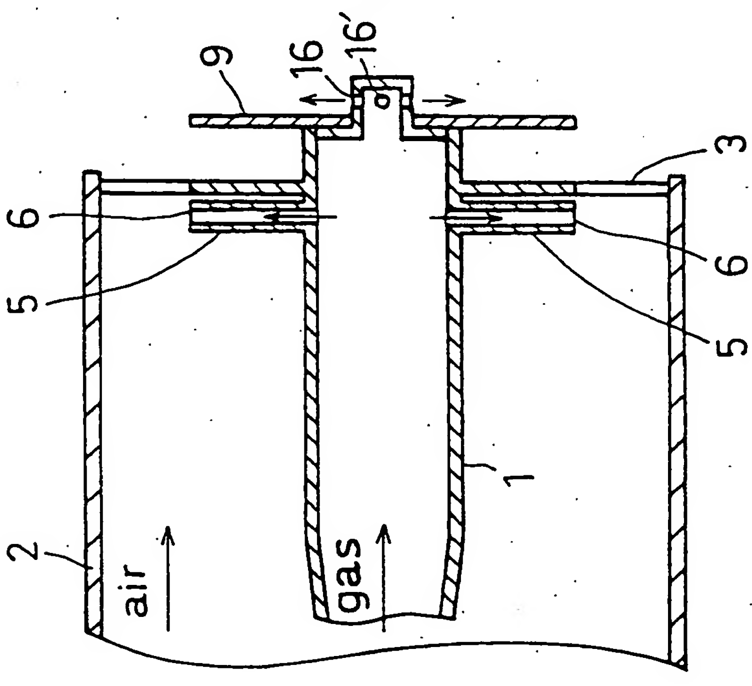


FIG 3A

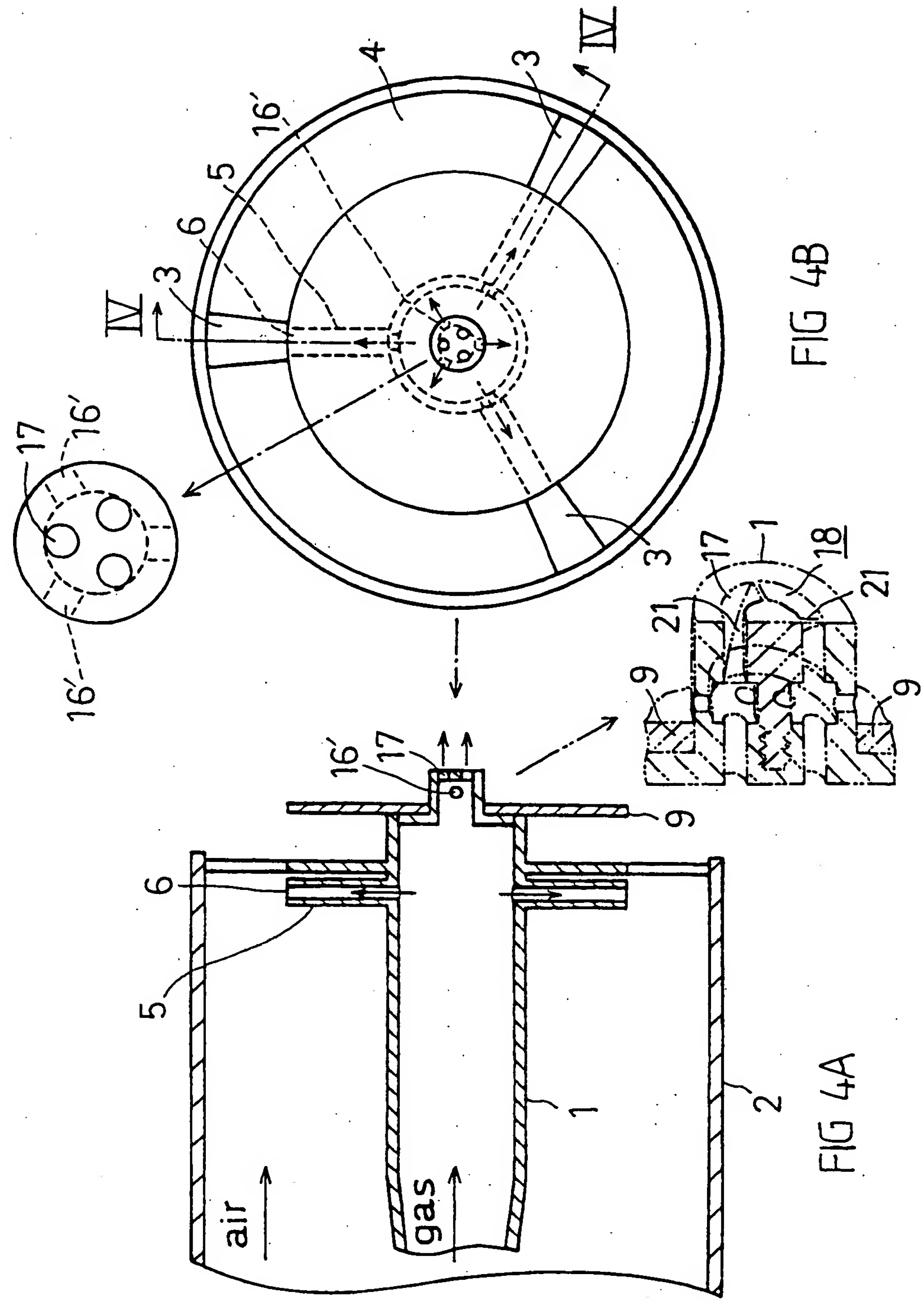


FIG 4B

FIG 4A

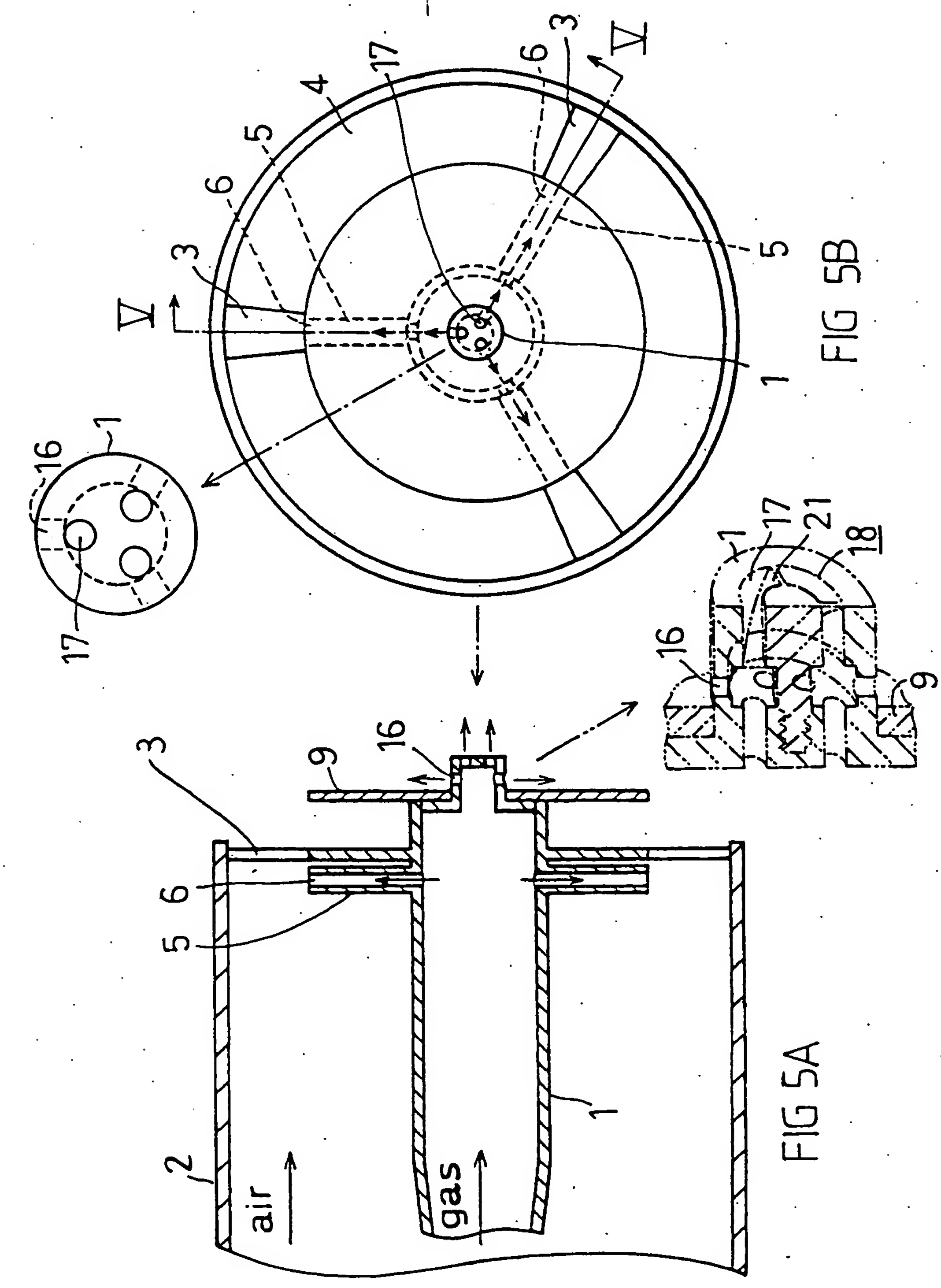


FIG 5A

FIG 5B

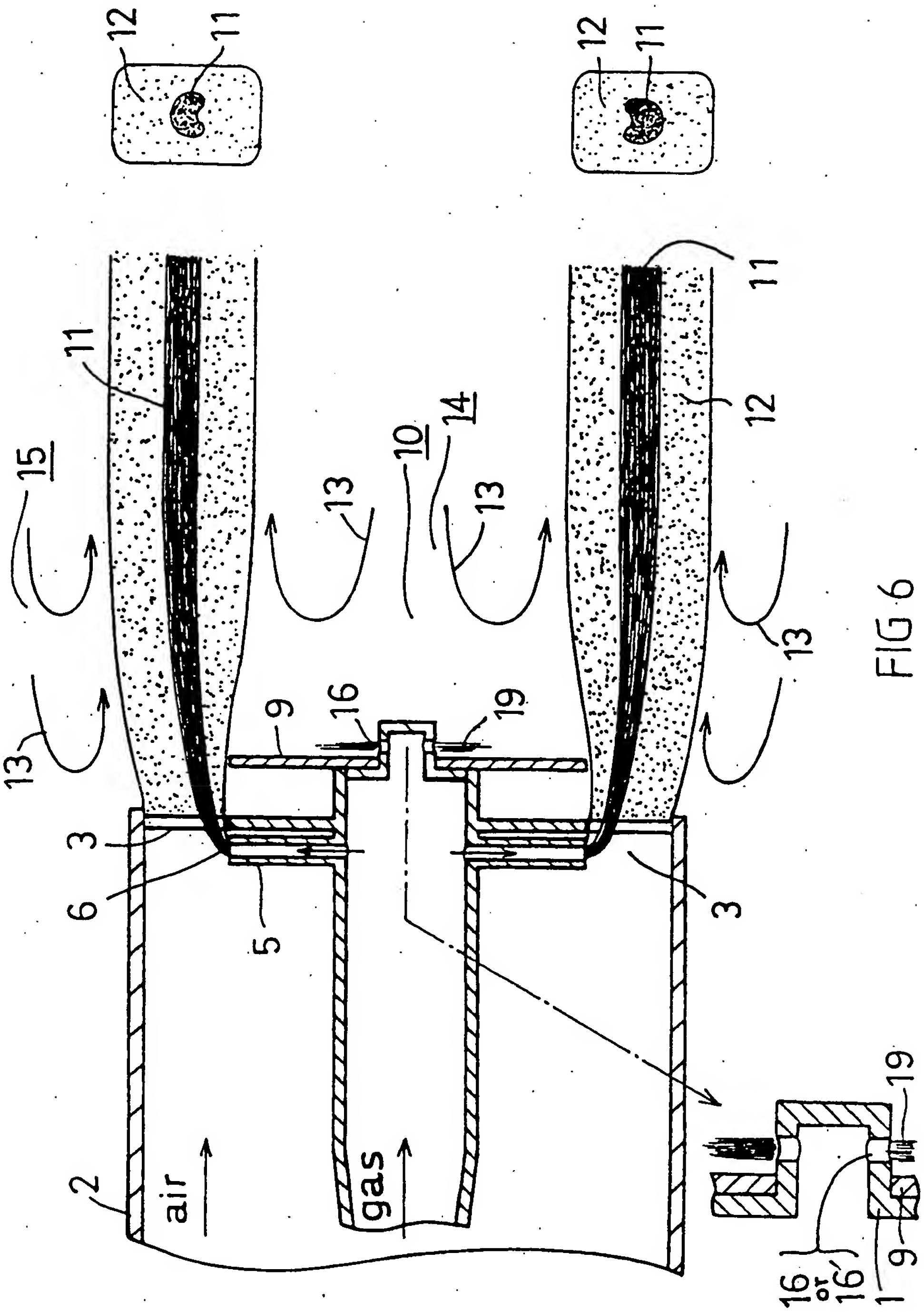


FIG 6

FIG 7

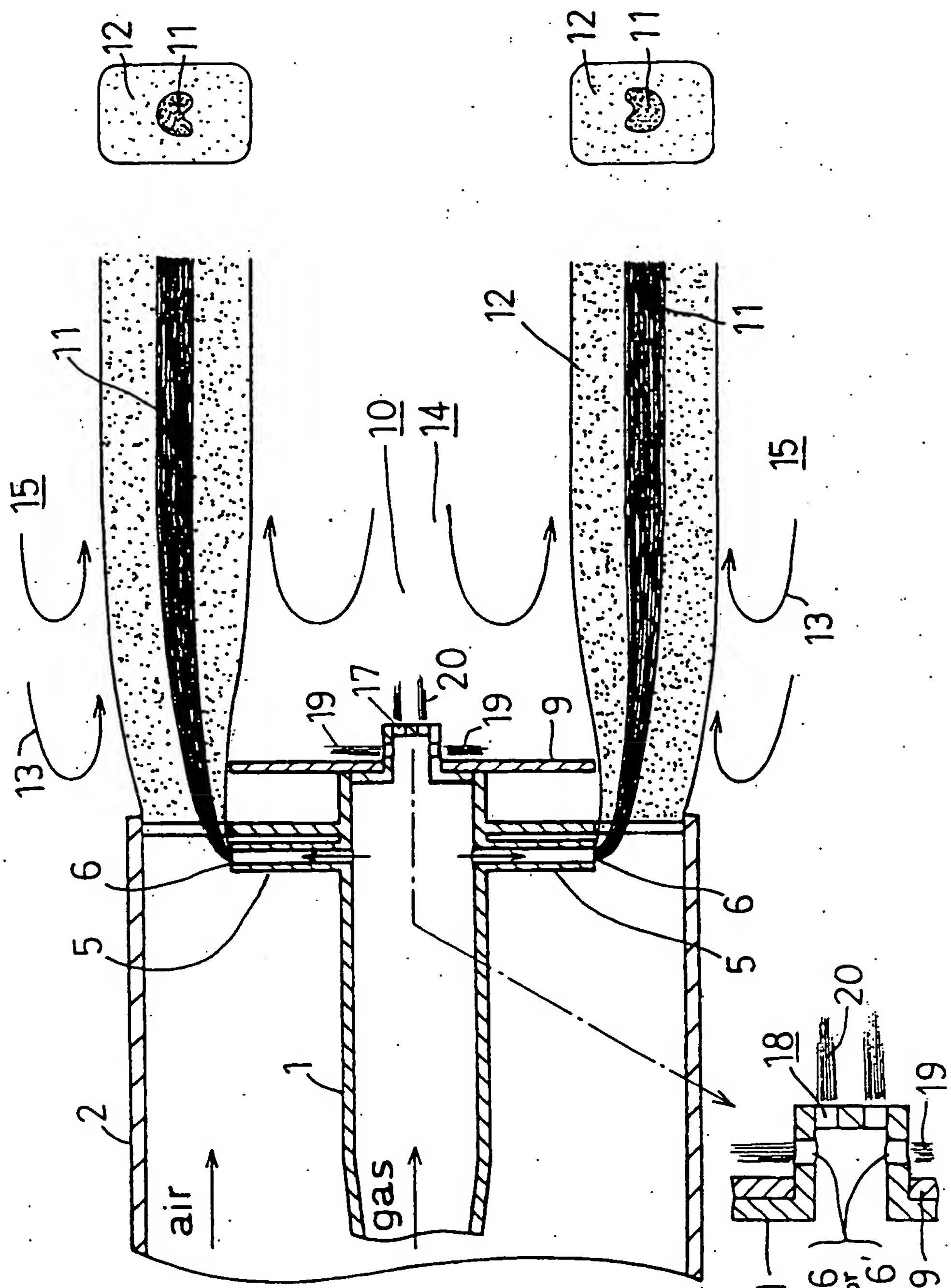


FIG. 8

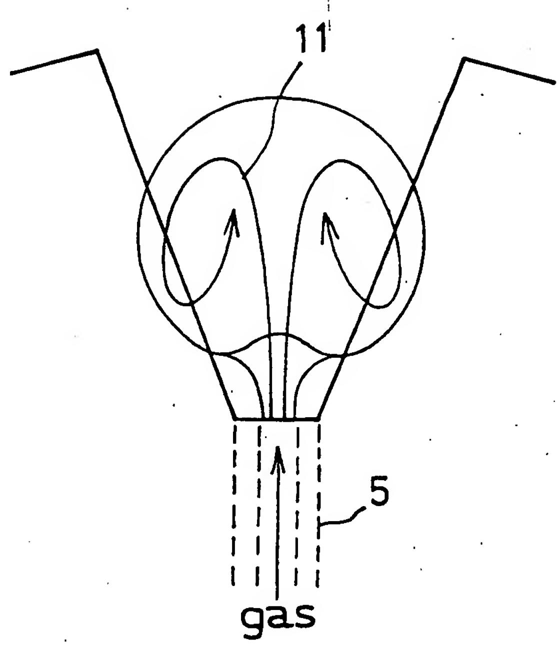


FIG. 9

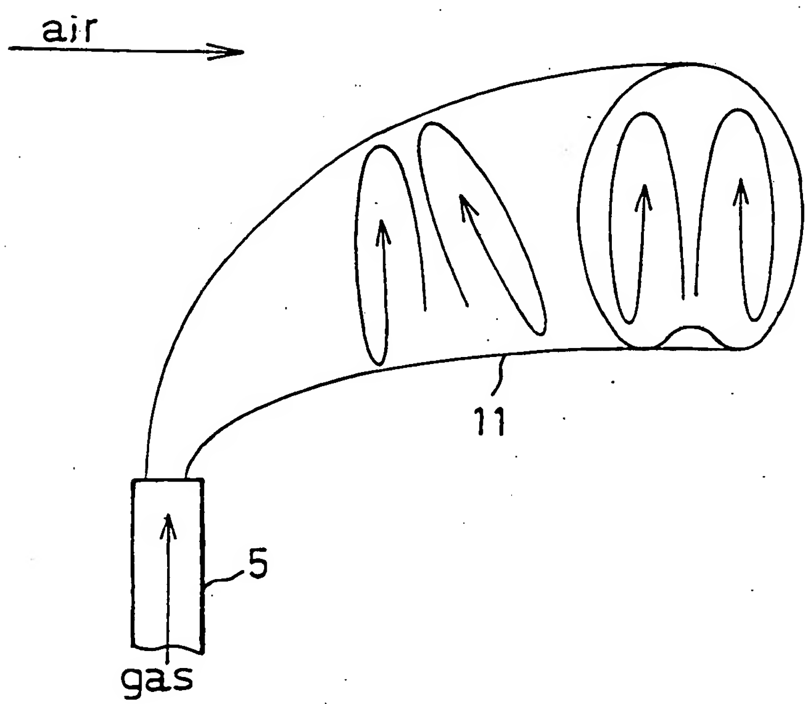


FIG.10

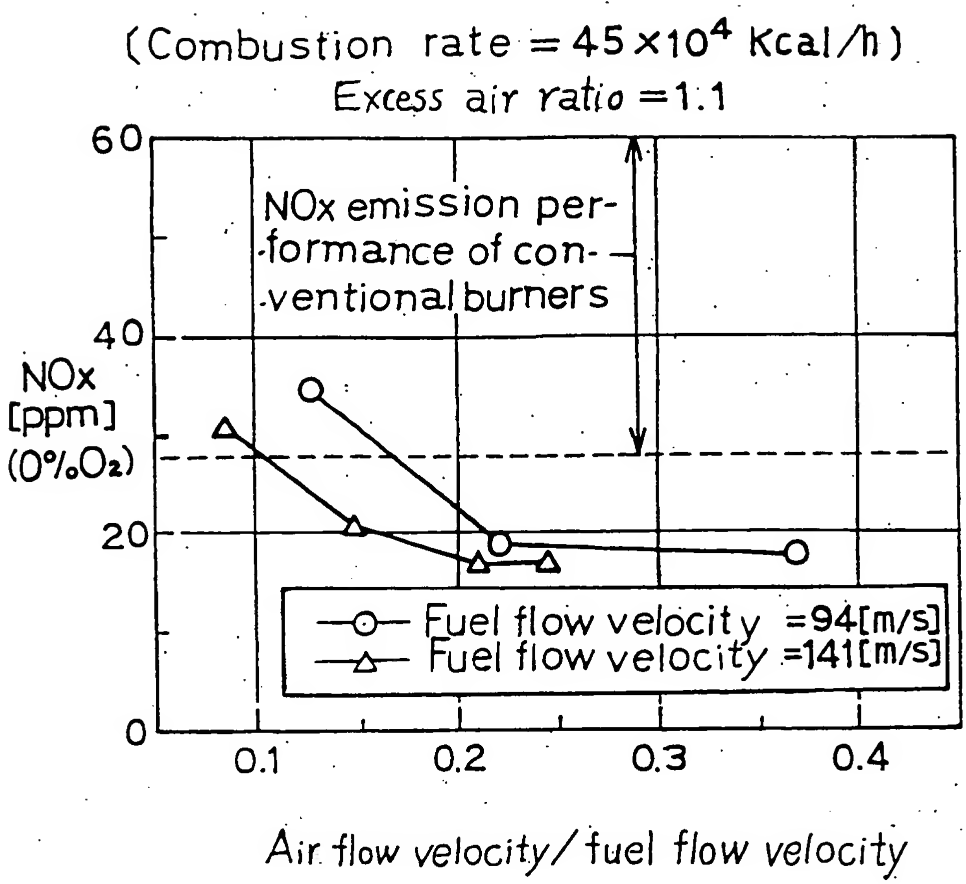

(Combustion rate = 45×10⁴ Kcal/h)
Excess air ratio = 1.1
60
40
20
0
NOx
[ppm]
(0%O₂)
NOx emission performance of conventional burners
Fuel flow velocity =94[m/s]
Fuel flow velocity =141[m/s]
0.1
0.2
0.3
0.4
Air flow velocity/ fuel flow velocity

FIG.11

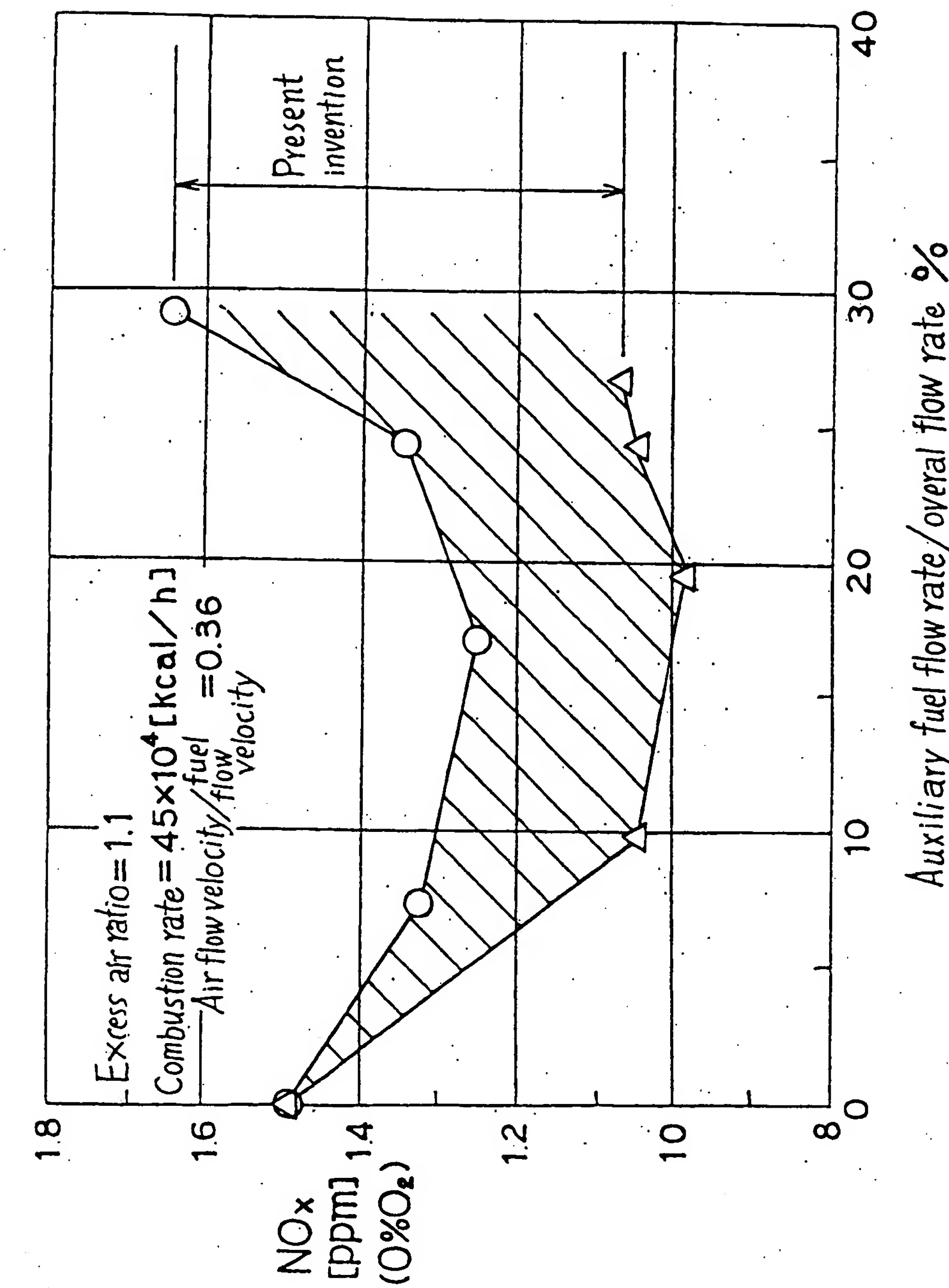
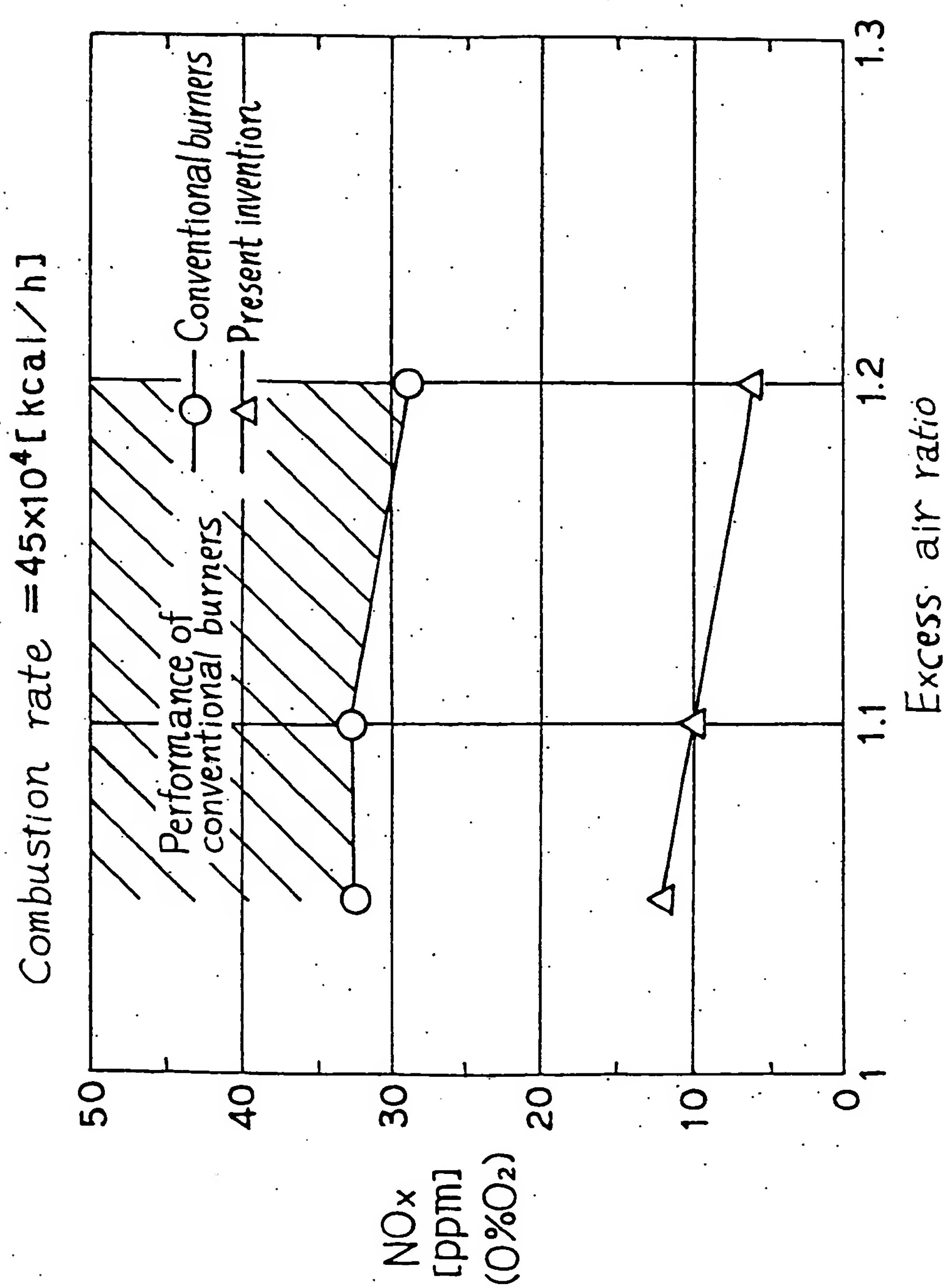

Excess air ratio=1.1
Combustion rate=45×10⁴[kcal/h]
Air flow velocity/fuel flow velocity =0.36
Present invention
NOx [ppm] (0%O₂)
1.8
1.6
1.4
1.2
1.0
8
0
10
20
30
40
Auxiliary fuel flow rate/overal flow rate %

FIG.12


Combustion rate =45x10⁴[kcal/h]
Conventional burners
Present invention
Performance of conventional burners
NOx [ppm] (0%O2)
50
40
30
20
10
0
1
1.1
1.2
1.3
Excess air ratio

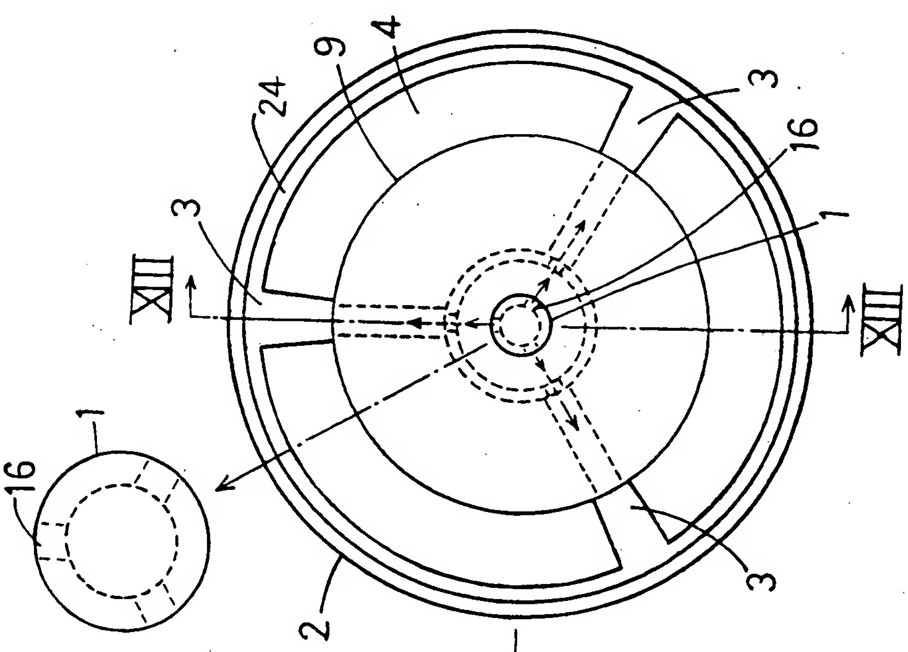


FIG 13B

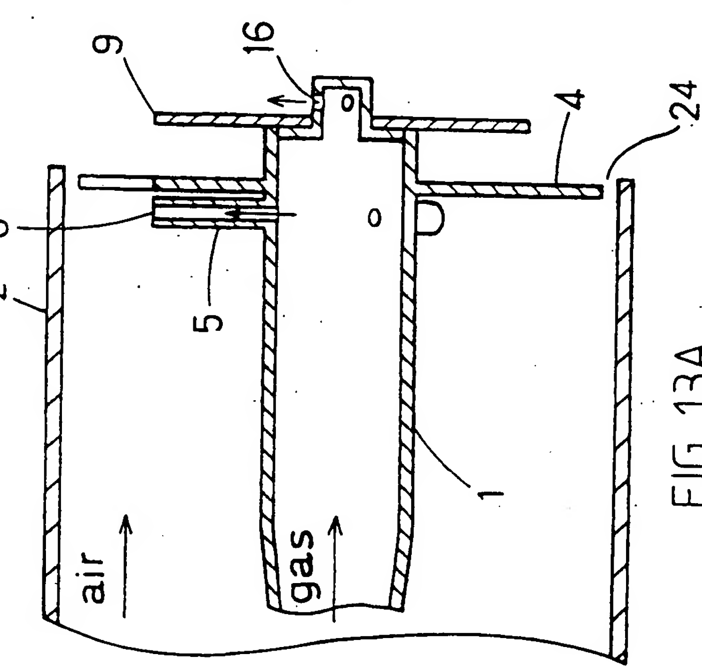


FIG 13A

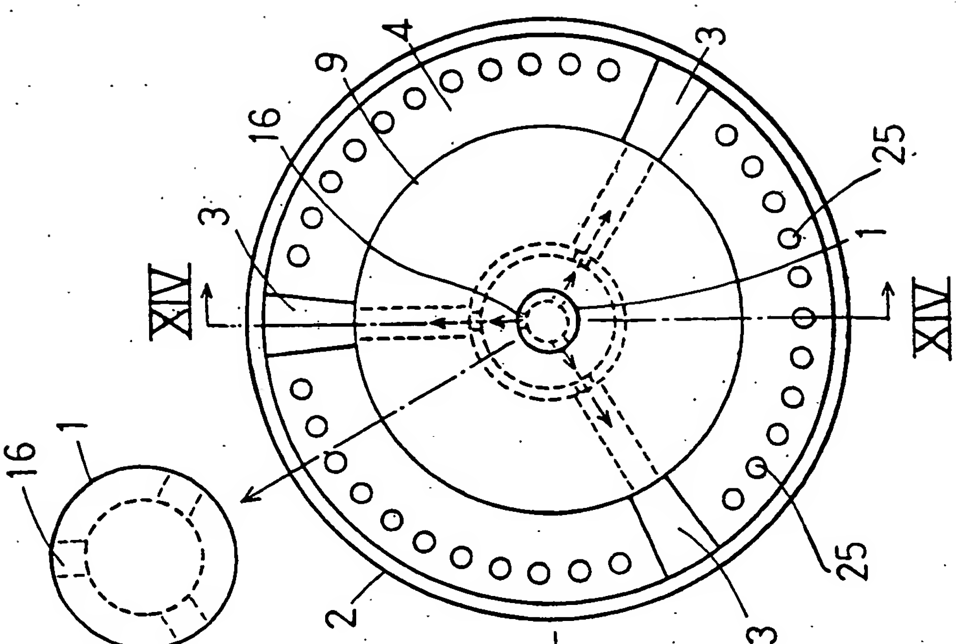


FIG 14B

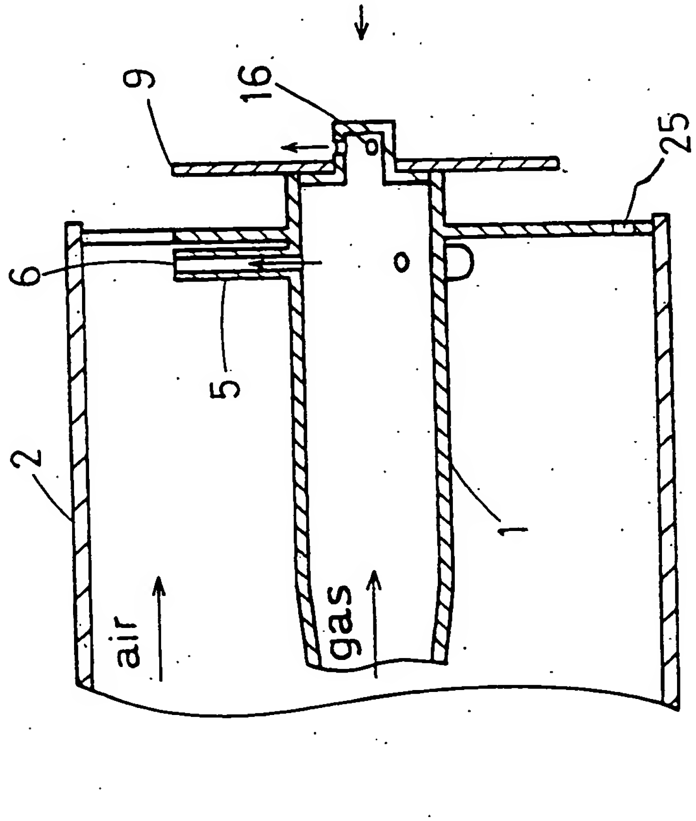


FIG 14A

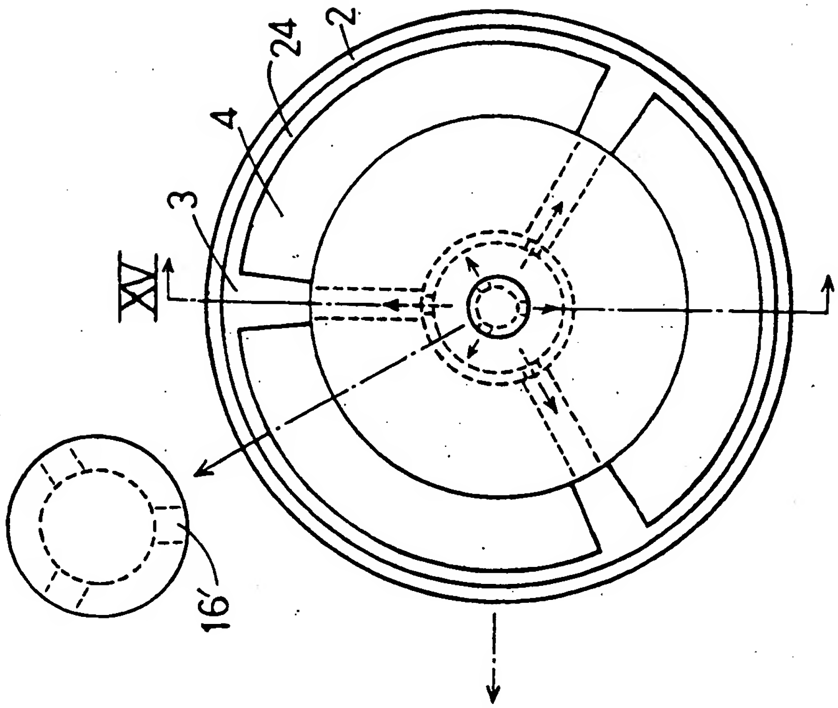


FIG 15B

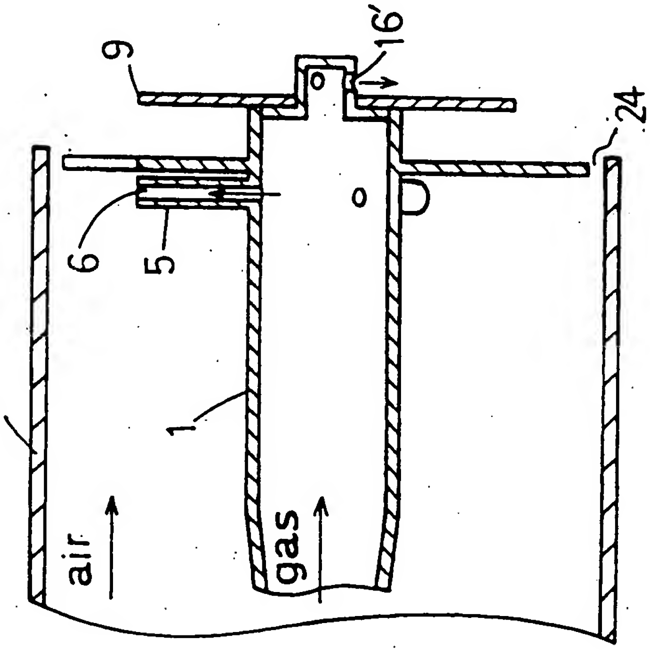


FIG 15A

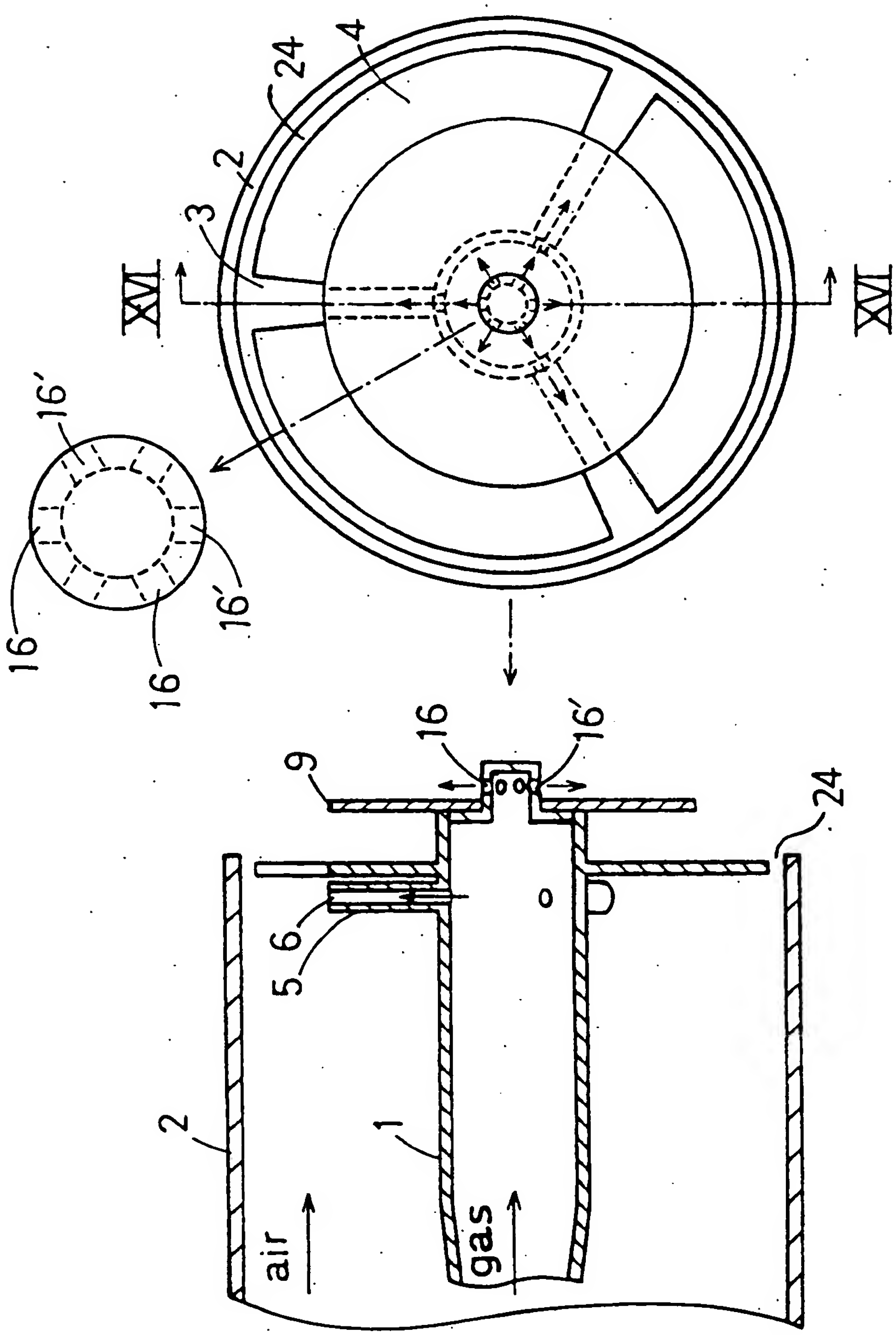


FIG 16B

FIG 16A

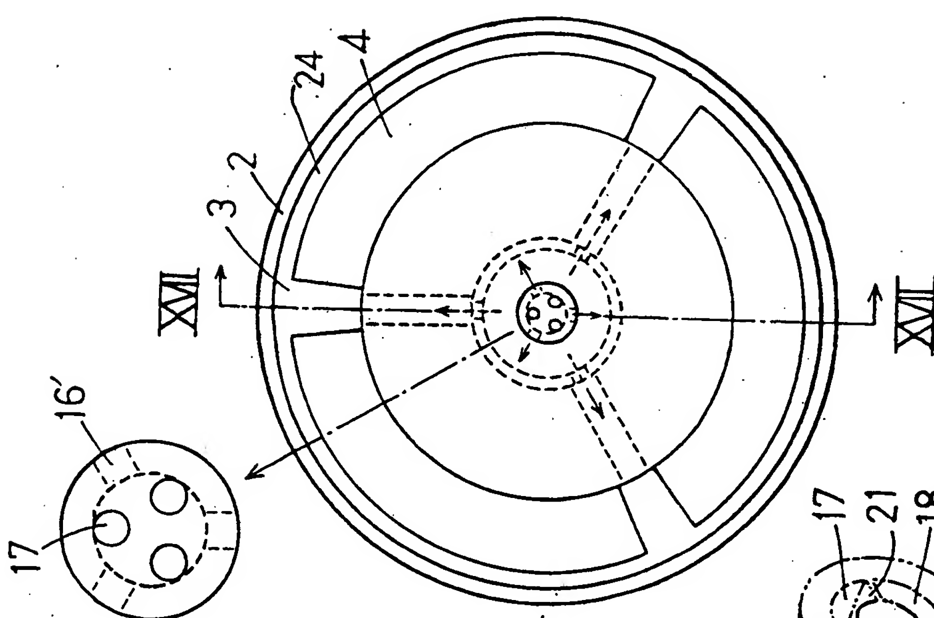


FIG 17B

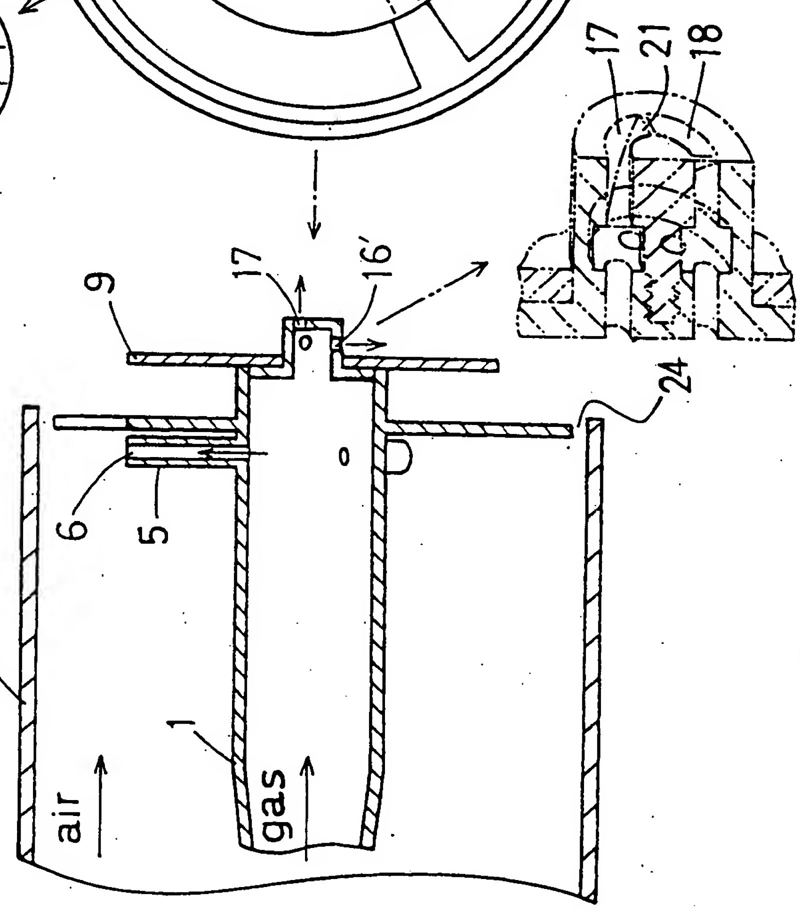


FIG 17A

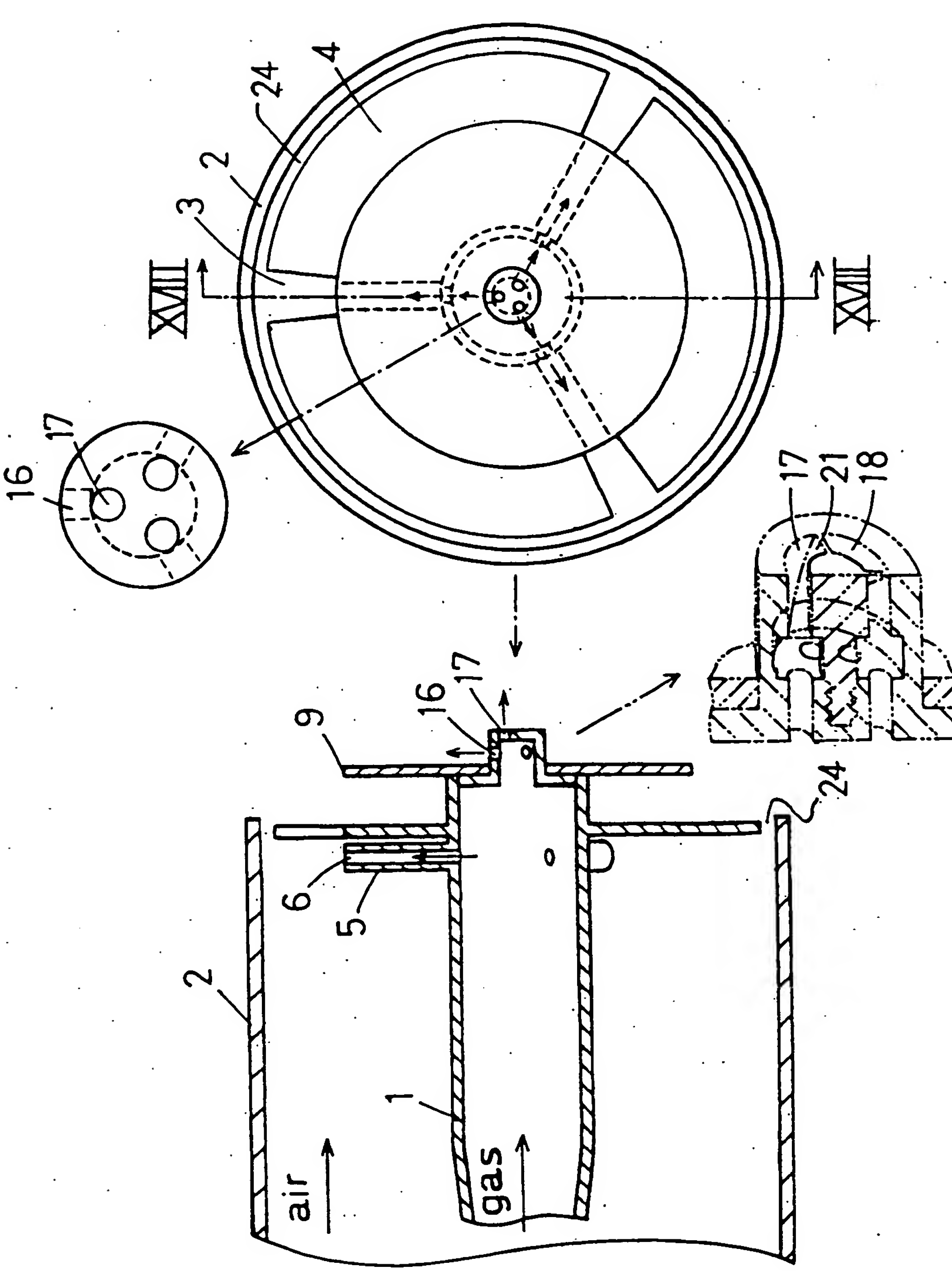


FIG 18A

FIG 18B

FIG 19

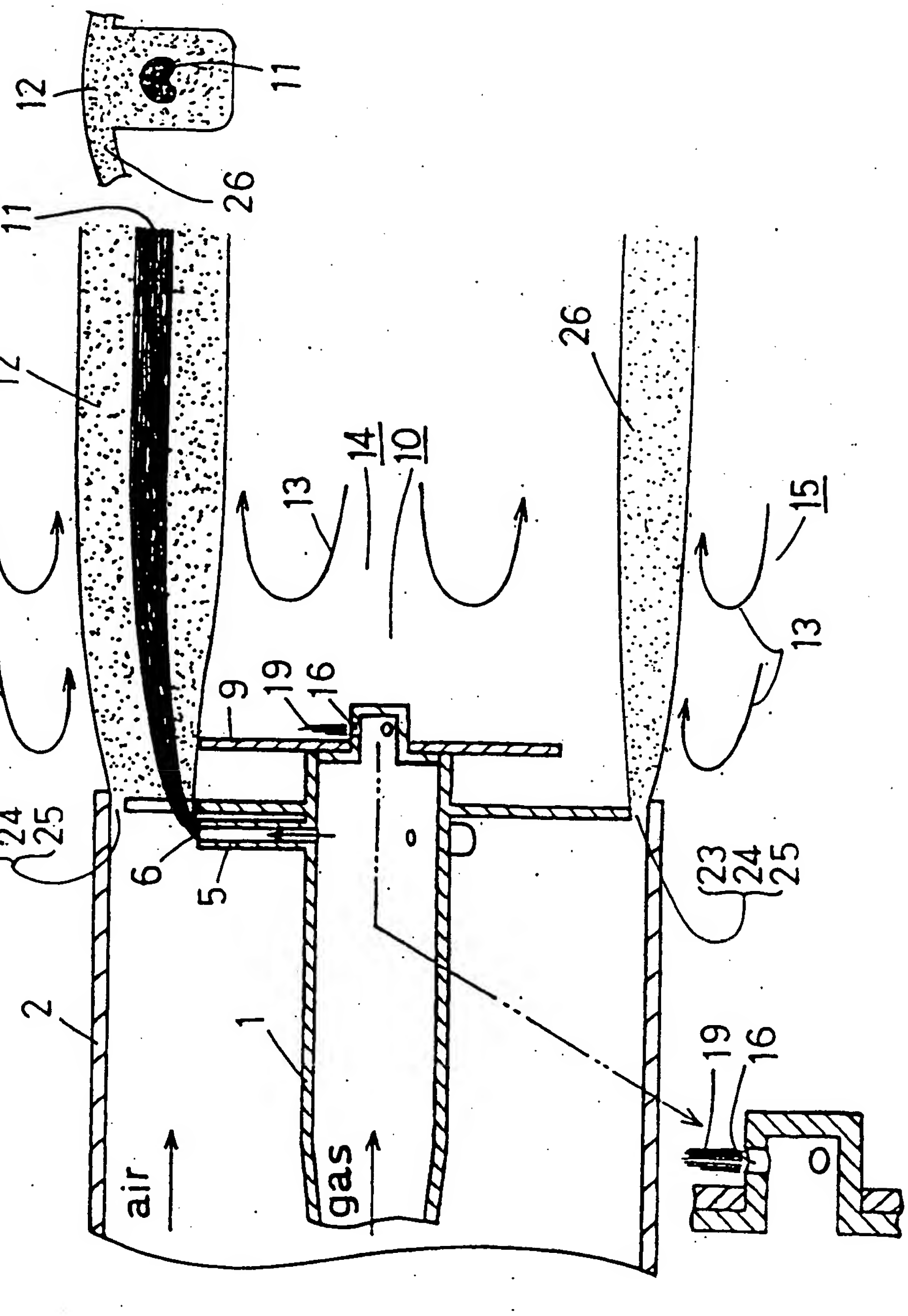
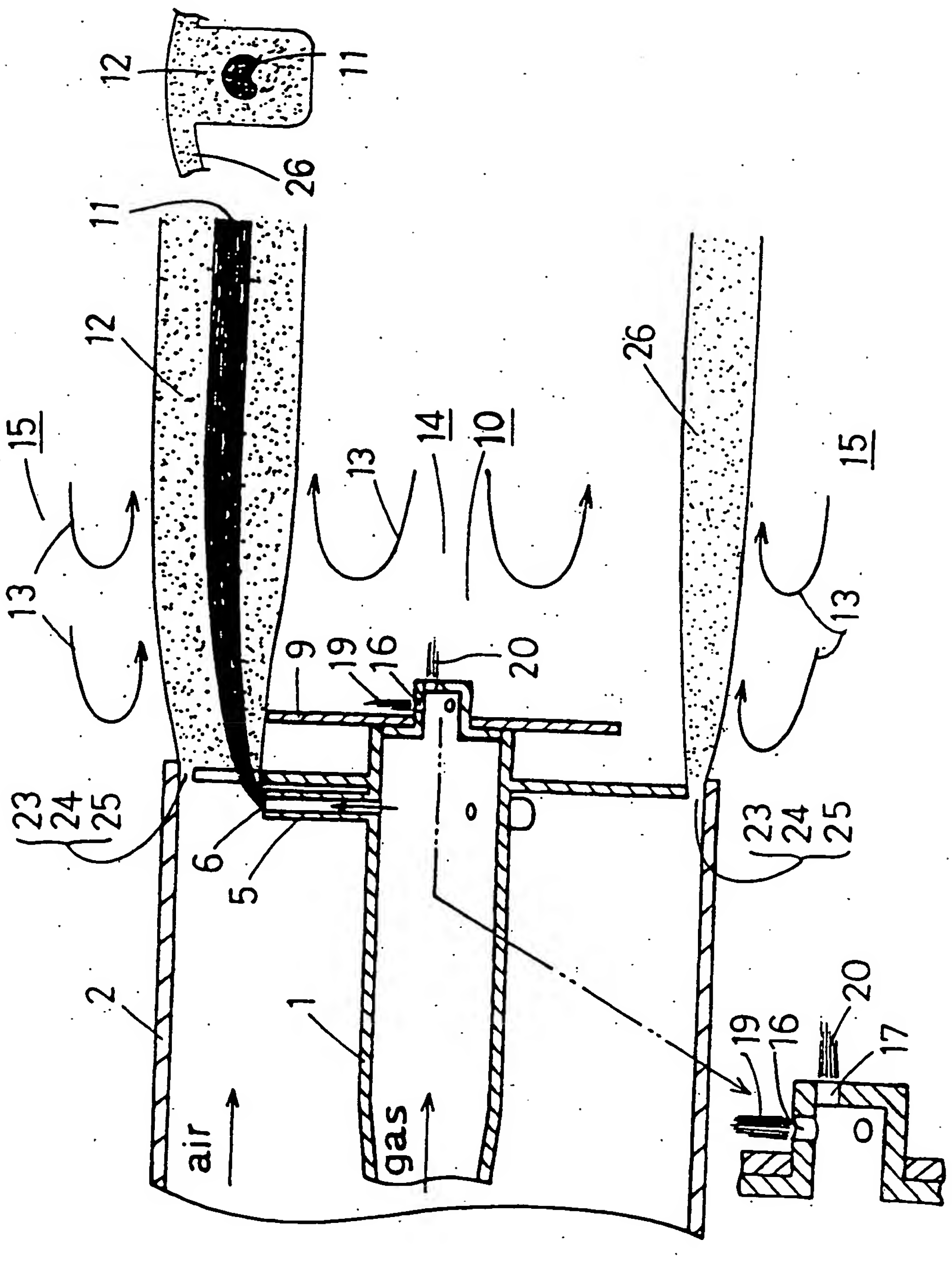


FIG 20



12
11
26
11
12
15
13
14
10
26
15
13
9
19
16
20
23
24
25
6
5
2
1
air
gas
19
16
20
17

FIG.21

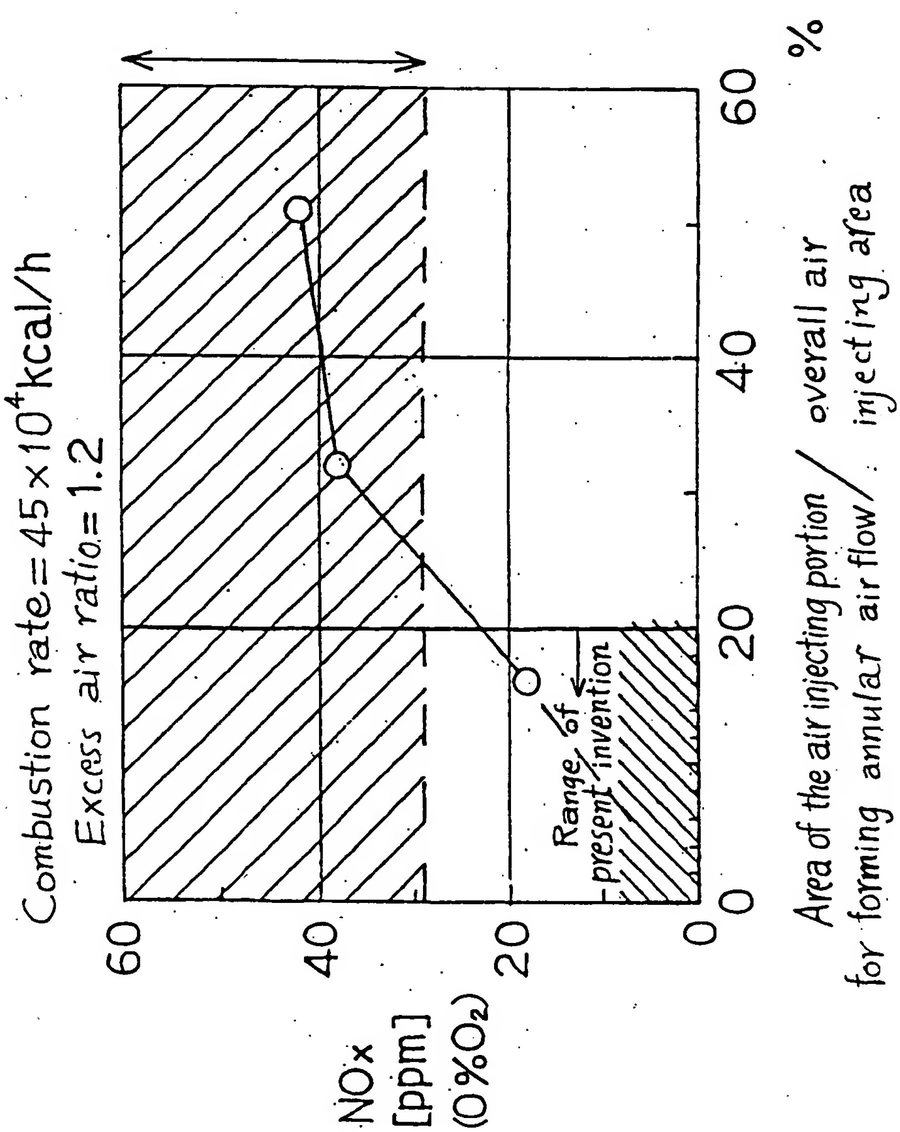
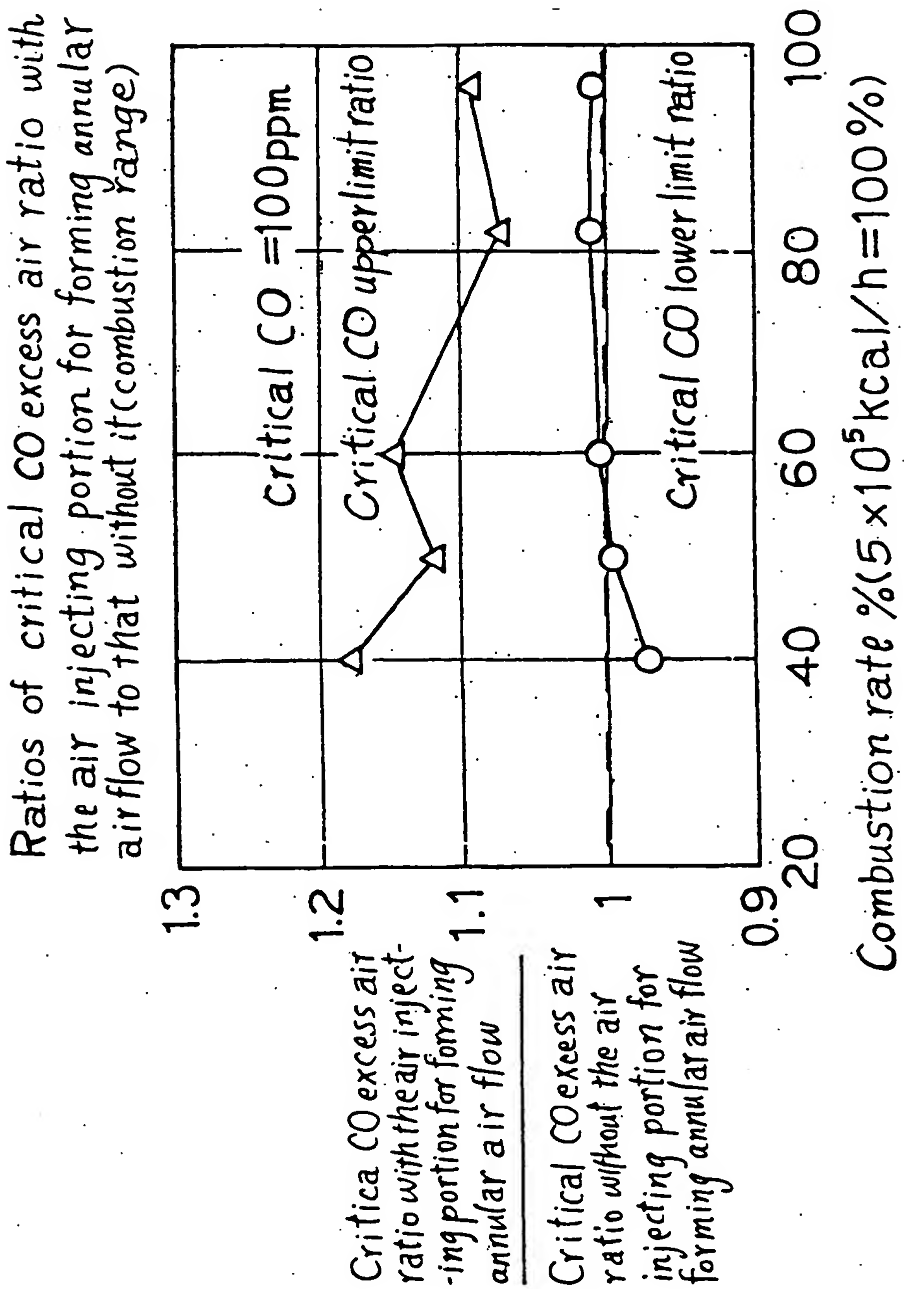

Combustion rate=45×10⁴kcal/h
Excess air ratio=1.2
NOx [ppm] (0%O2)
60
40
20
0
0
20
40
60
%
Range of present invention
Area of the air injecting portion for forming annular air flow / overall air injecting area

FIG. 22


Ratios of critical CO excess air ratio with the air injecting portion for forming annular air flow to that without it(combustion range)
1.3
1.2
1.1
1
0.9
20
40
60
80
100
Combustion rate %(5×10^5kcal/h=100%)
Critical CO =100ppm
Critical CO upper limit ratio
Critical CO lower limit ratio
Critica CO excess air ratio with the air inject-ing portion for forming annular air flow
Critical CO excess air ratio without the air injecting portion for forming annular air flow

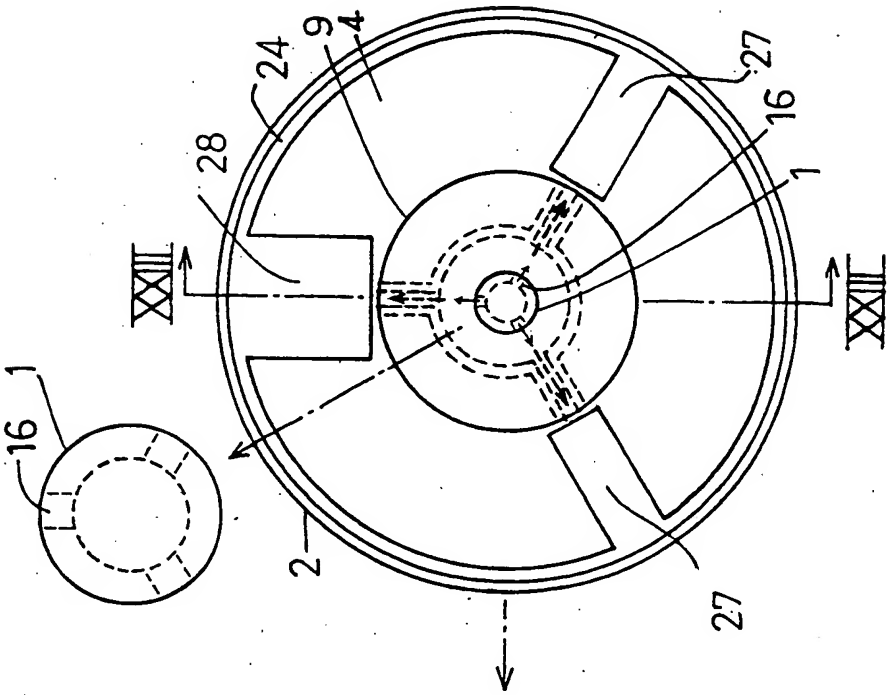


FIG 23B

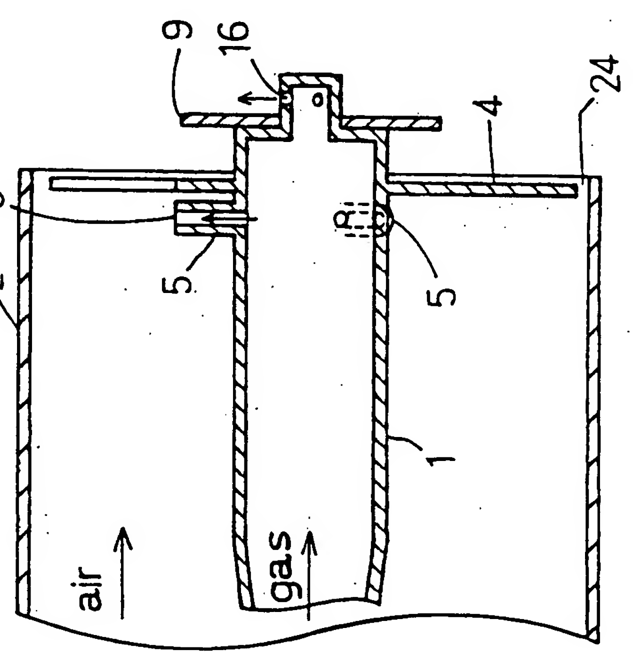


FIG 23A

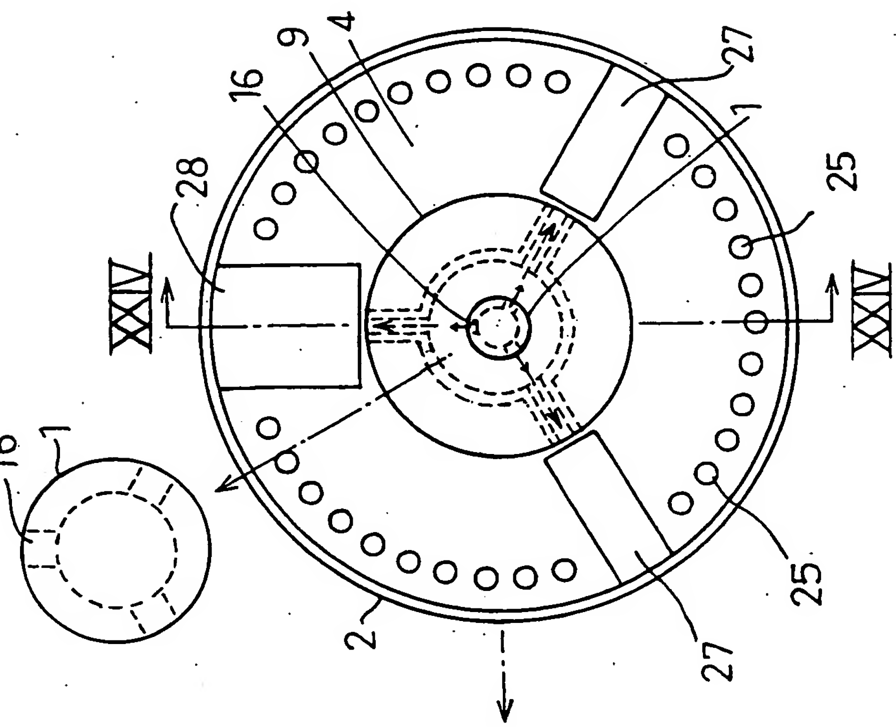


FIG 24B

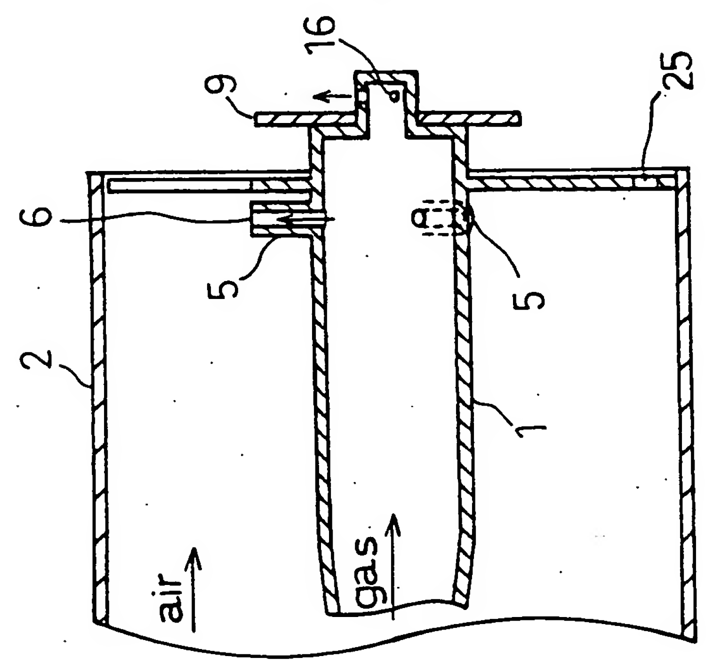


FIG 24A

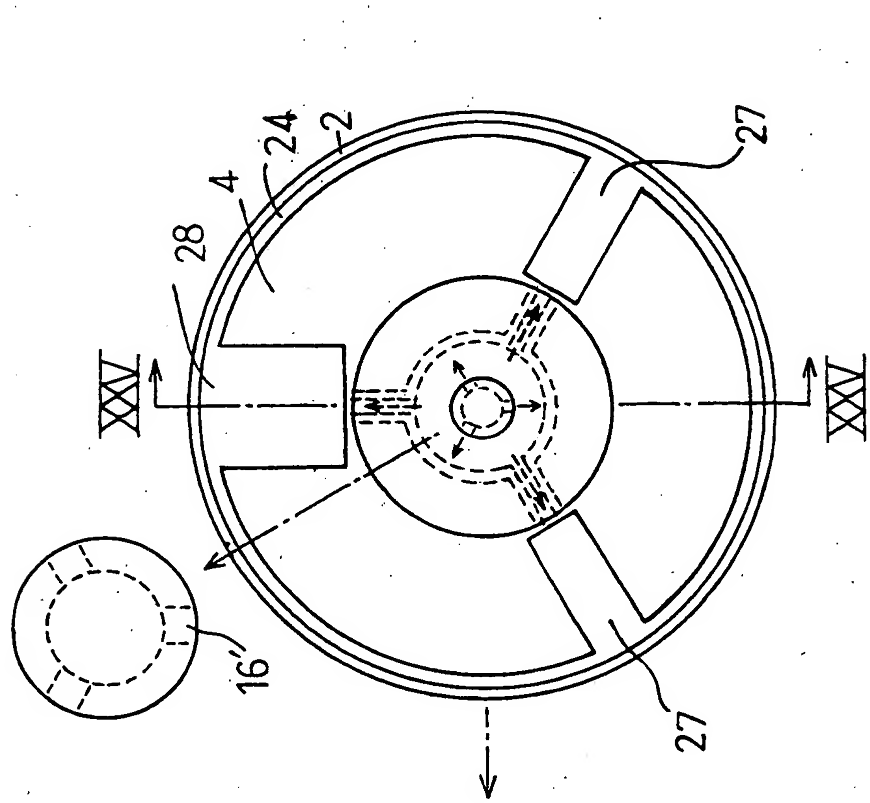


FIG 25B

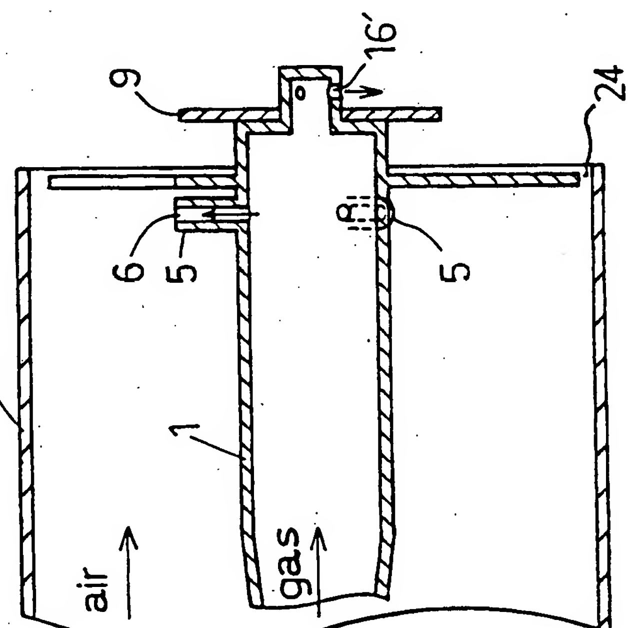


FIG 25A

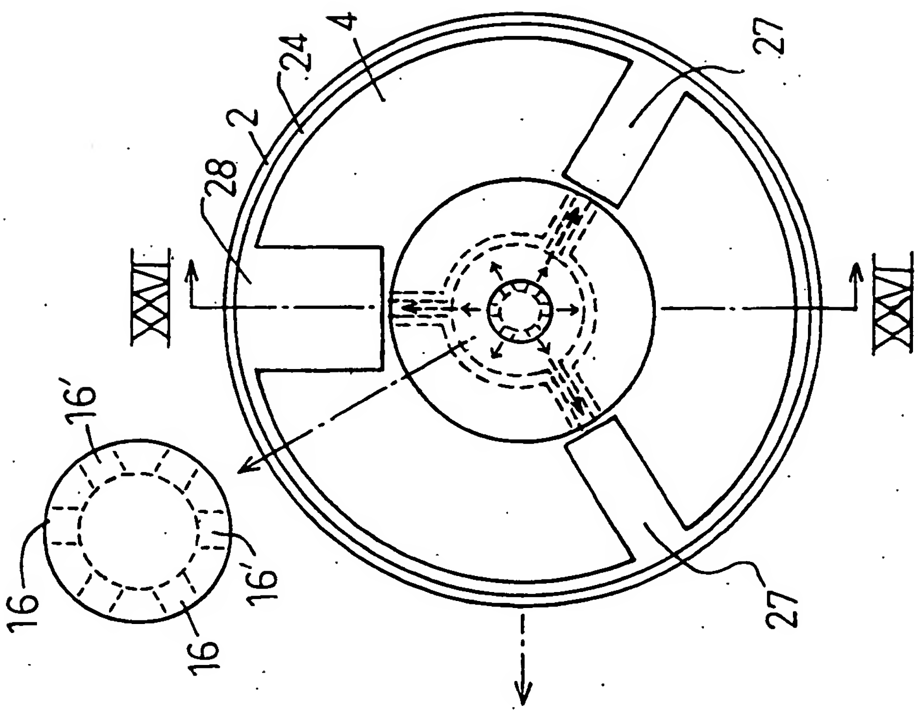


FIG 26B

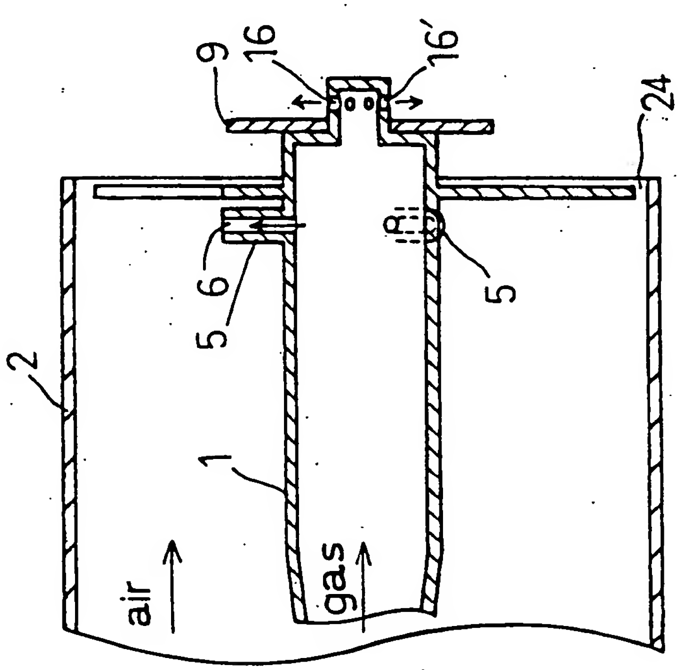


FIG 26A

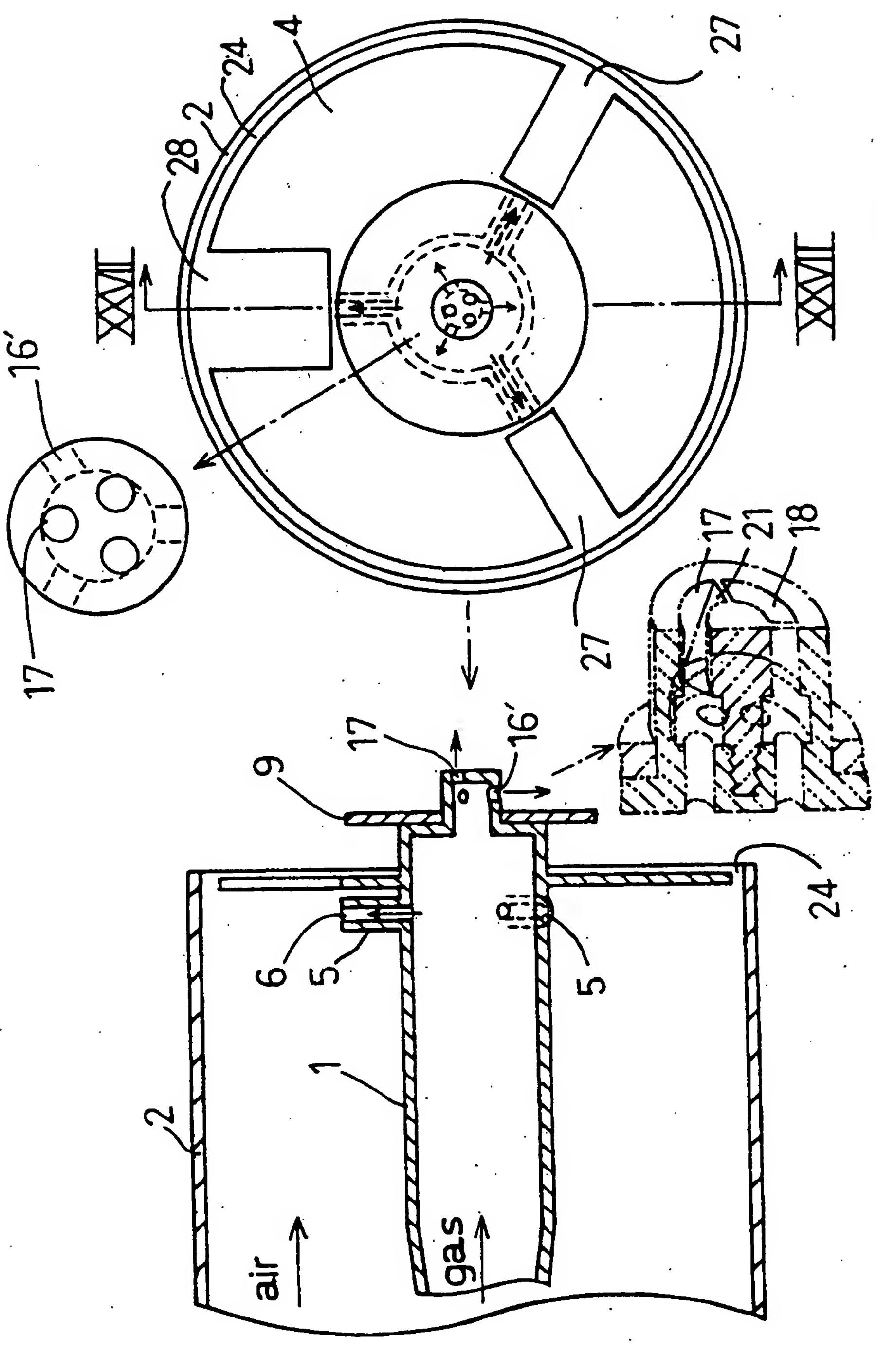


FIG 27A

FIG 27B

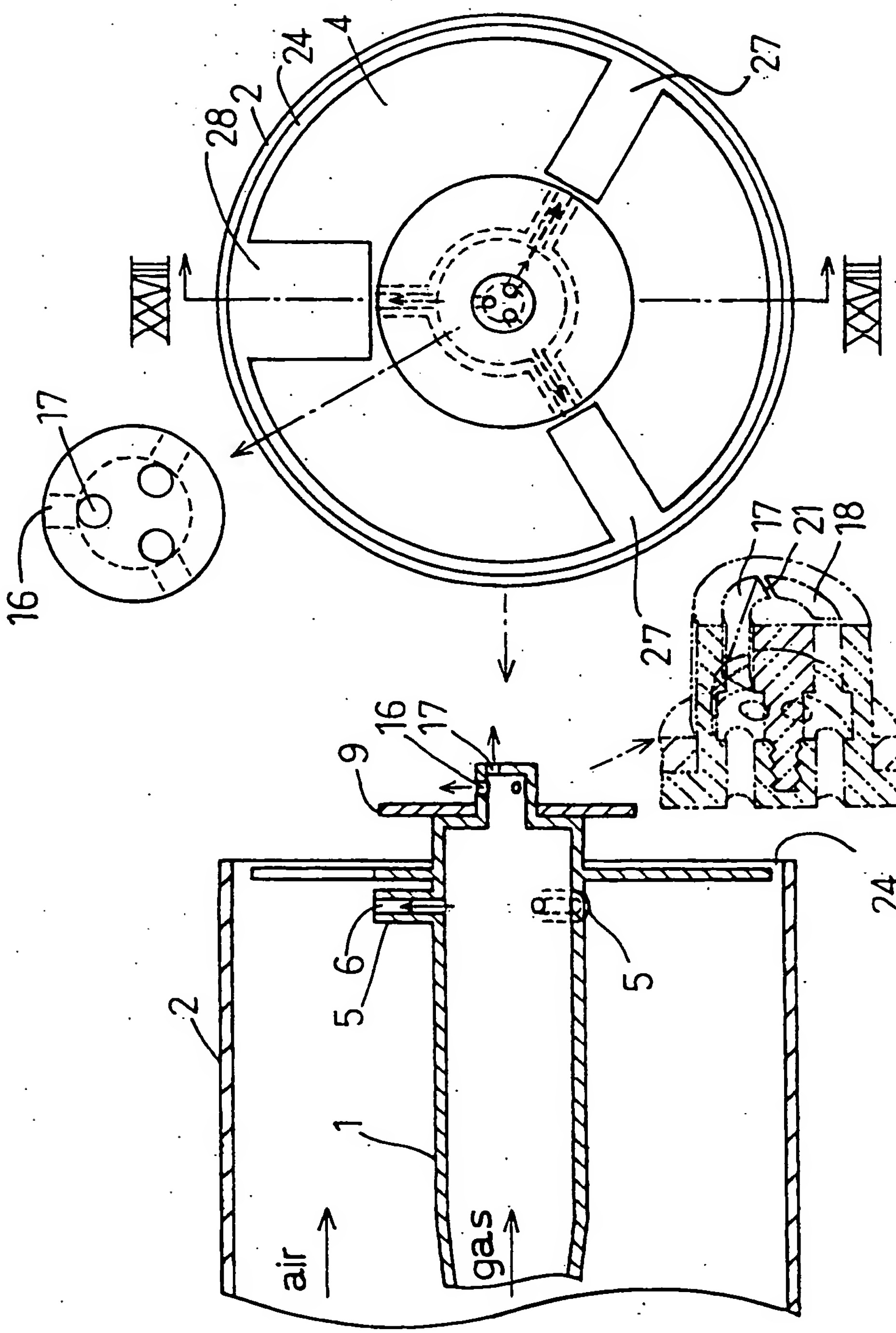


FIG 28B

FIG 28A

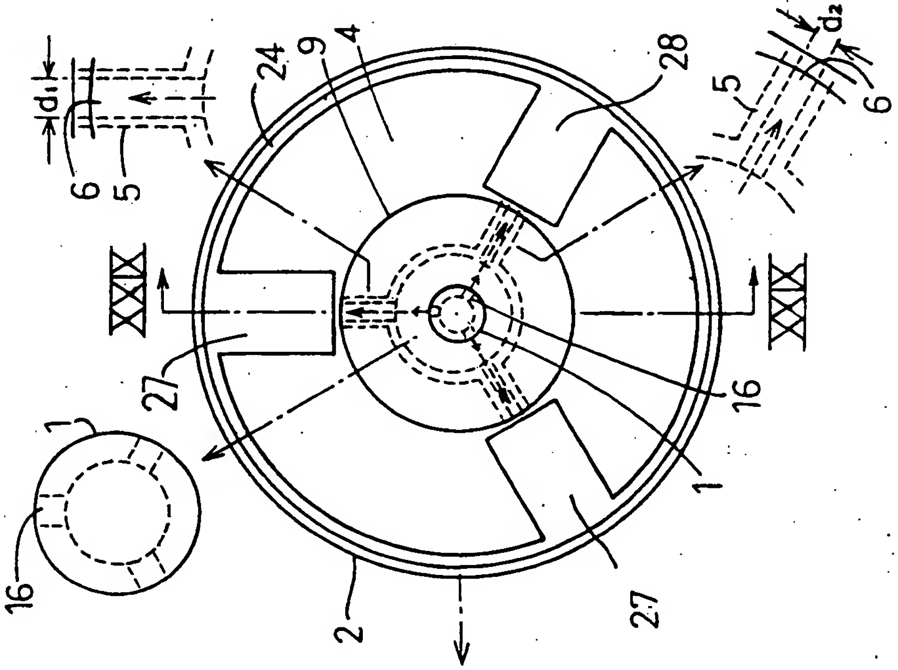


FIG 29B

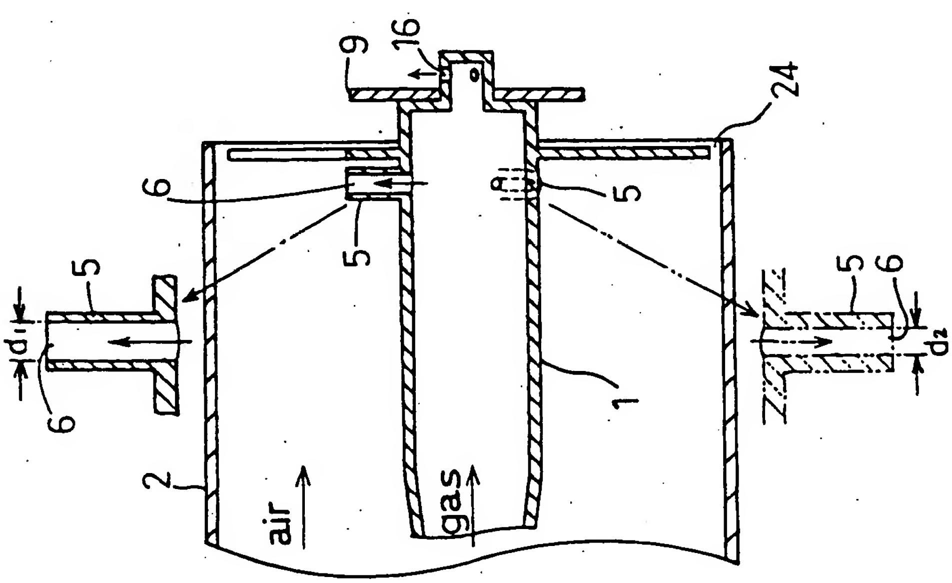


FIG 29A

FIG 30B

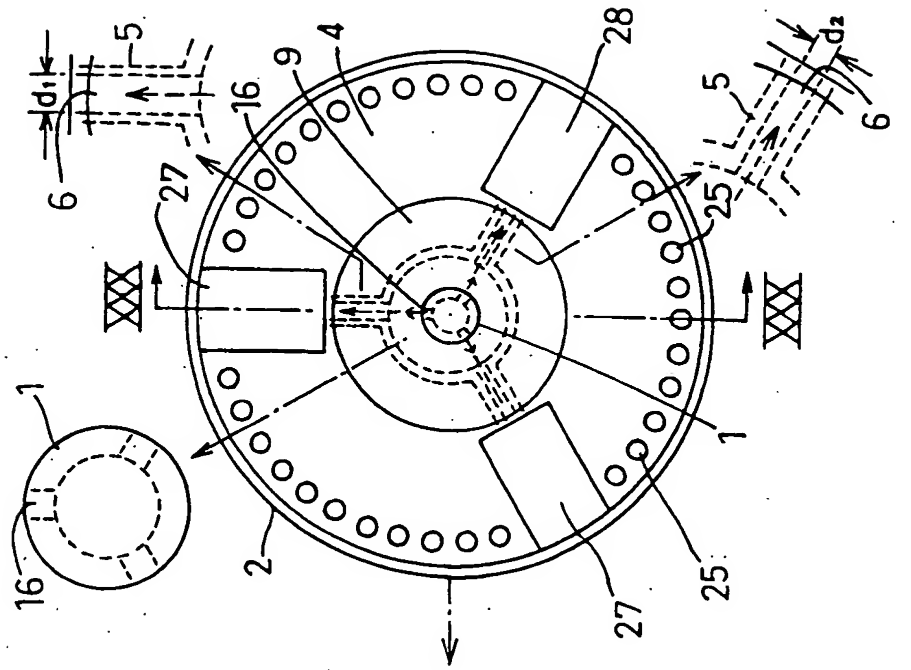


FIG 30A

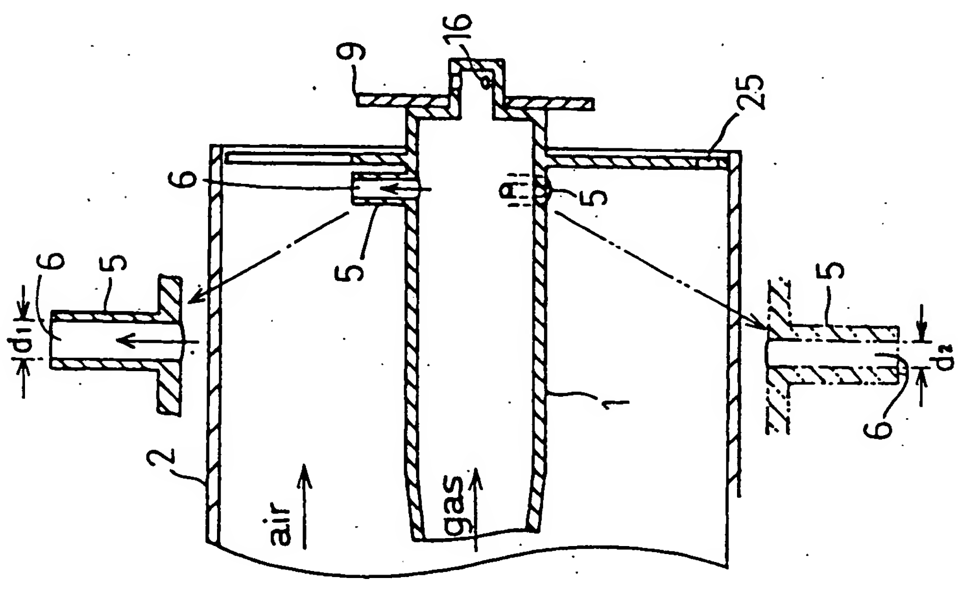


FIG 31B

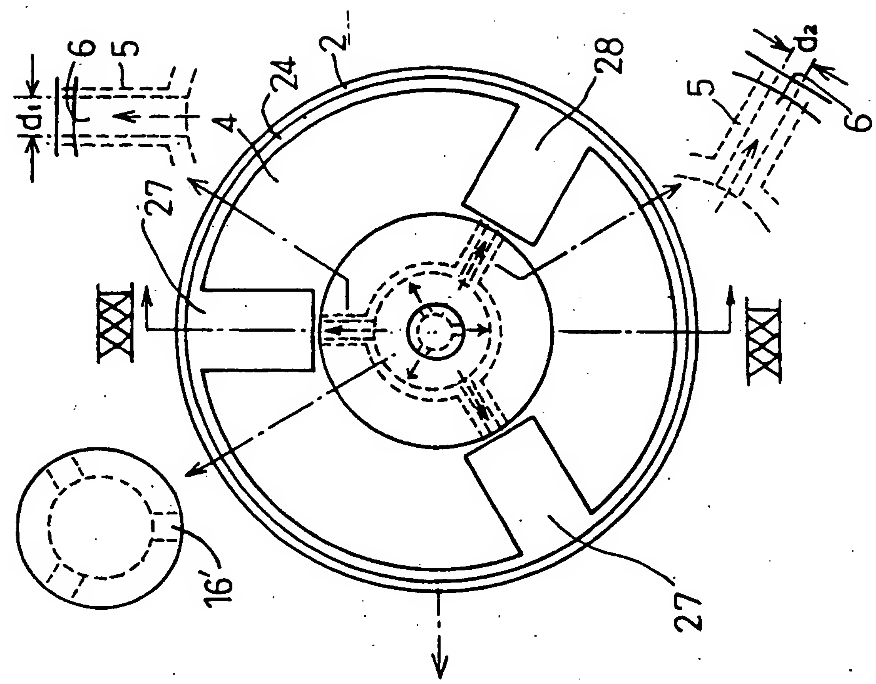


FIG 31A

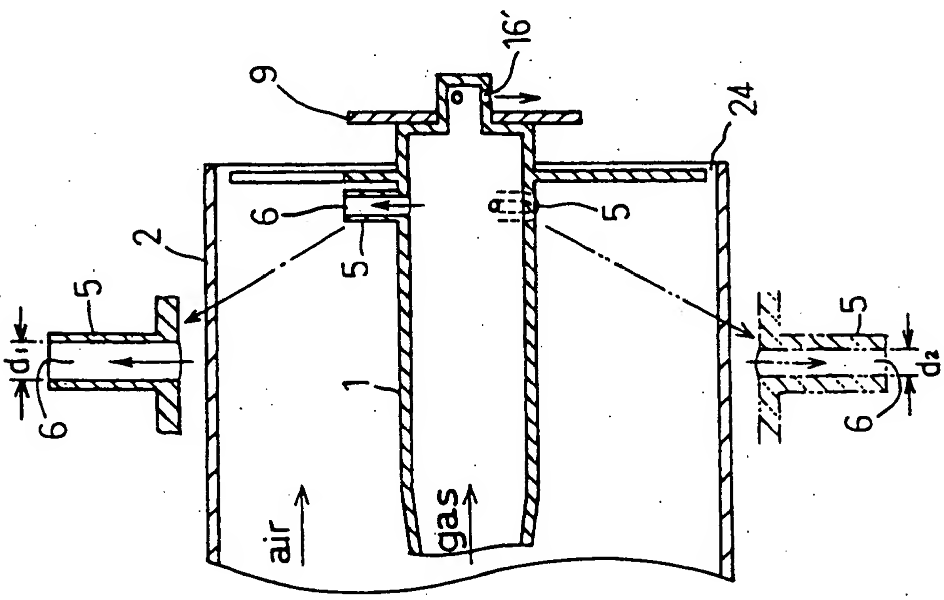


FIG 32A

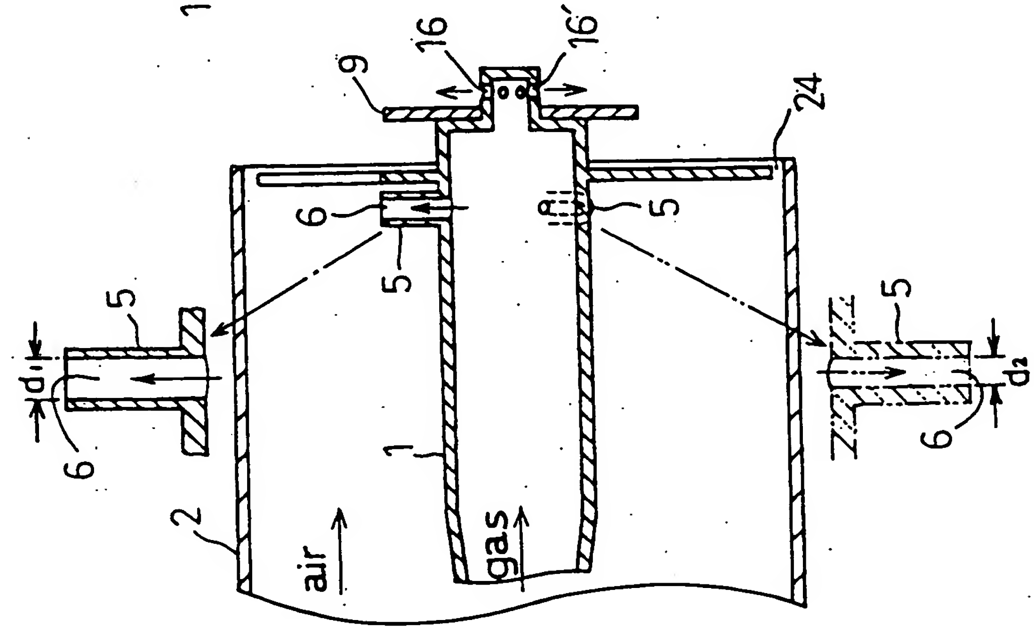


FIG 32B

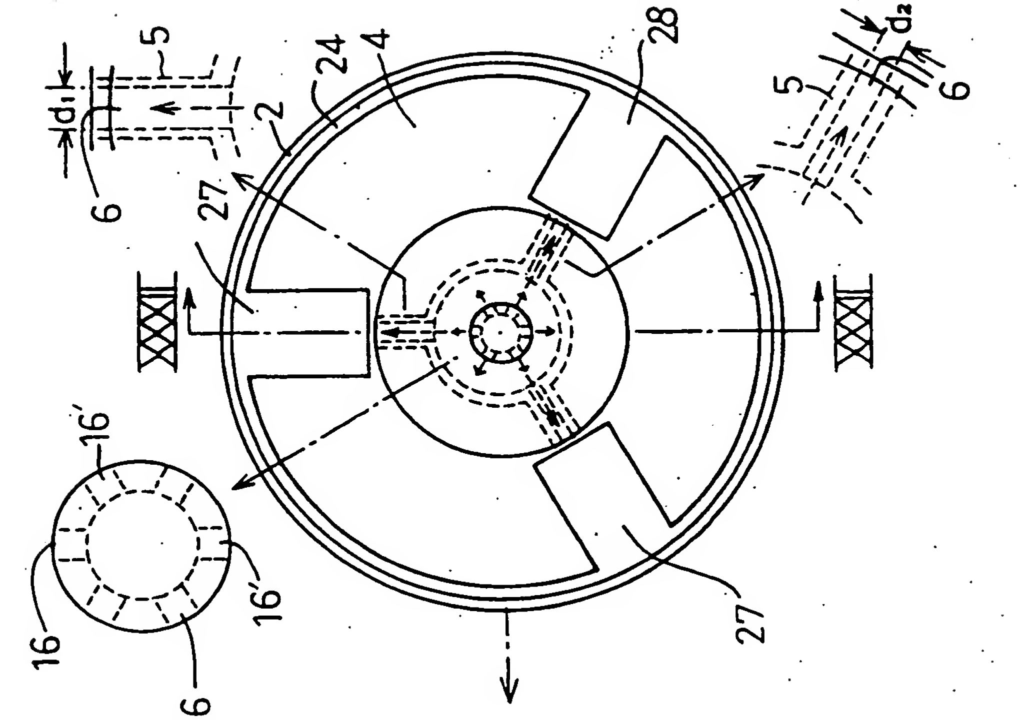


FIG 33A

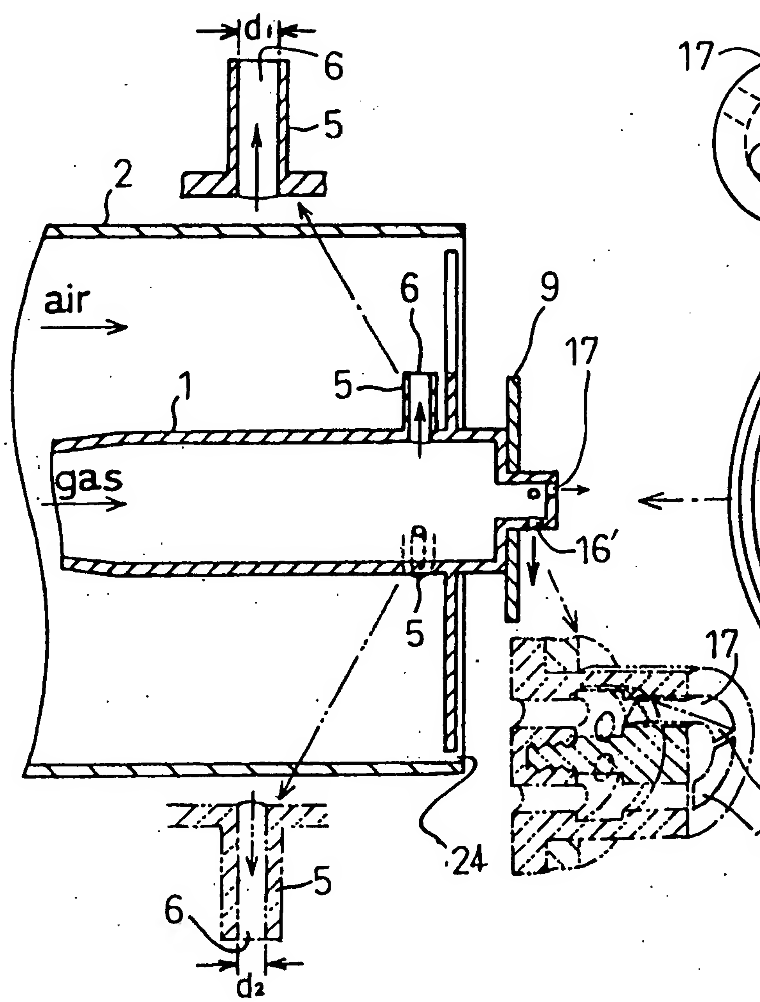


FIG 33B

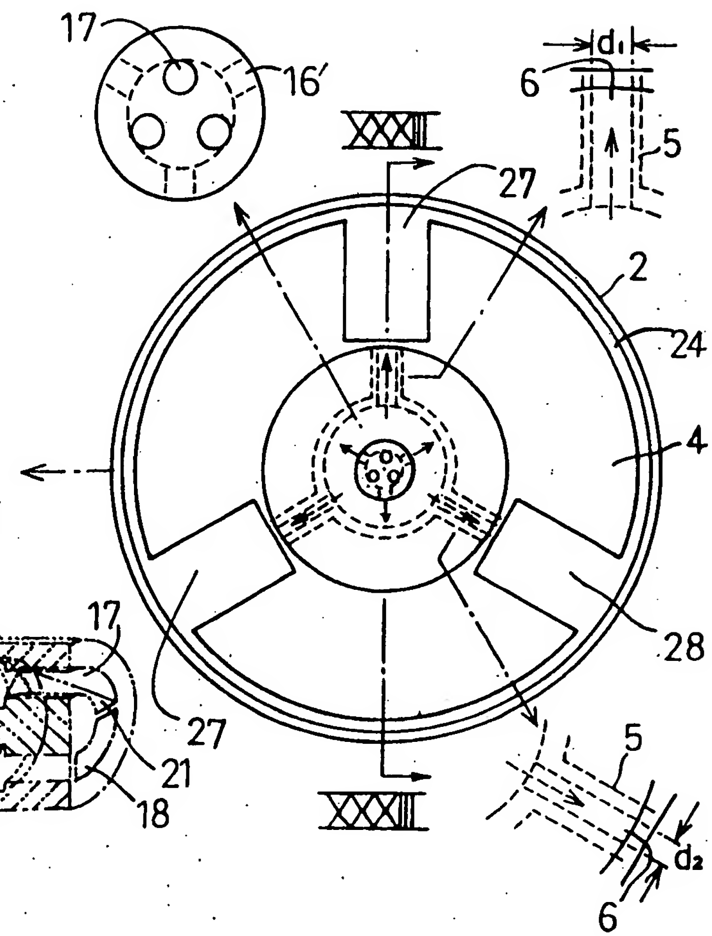


FIG 34B

FIG 34A

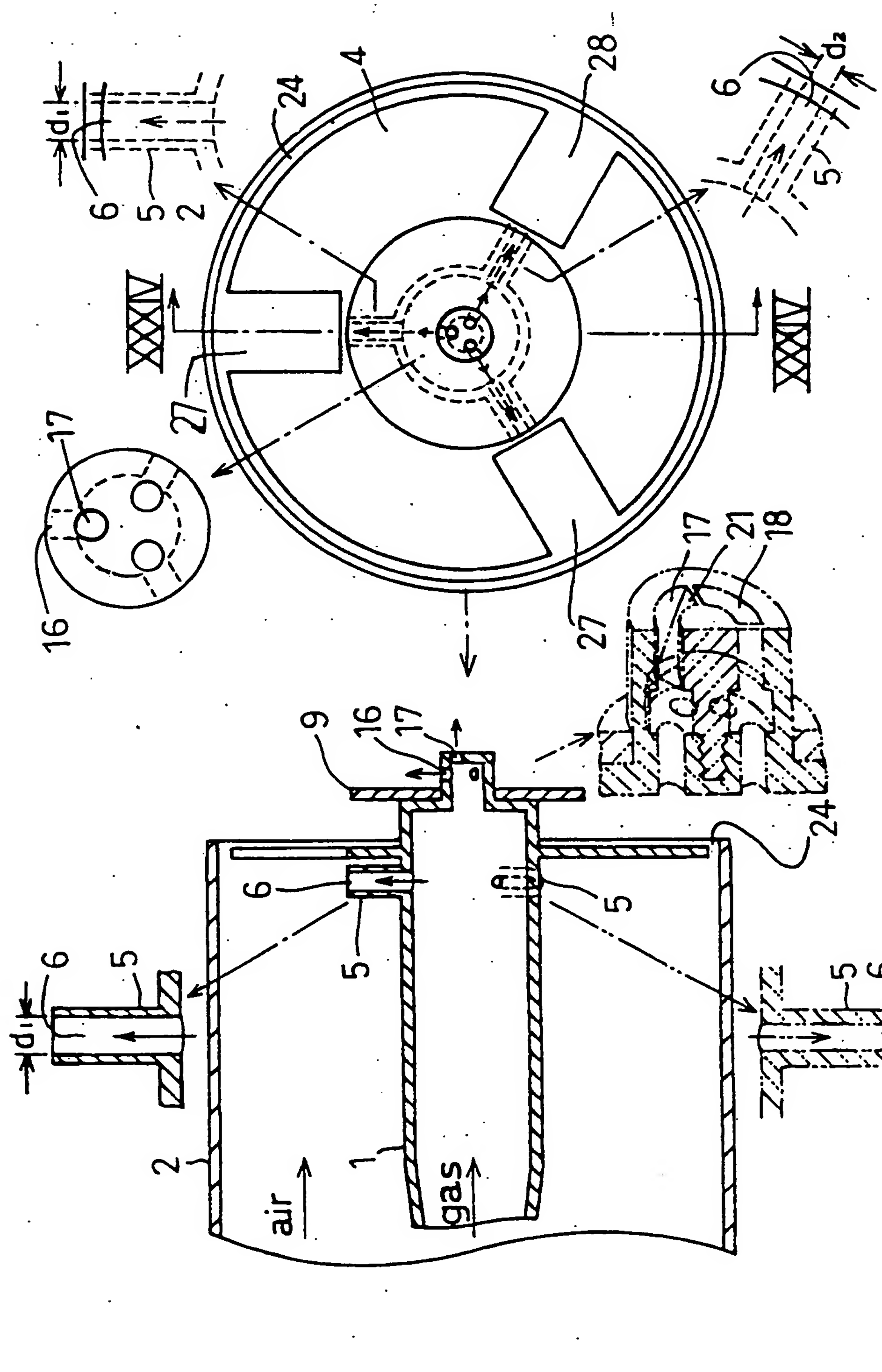
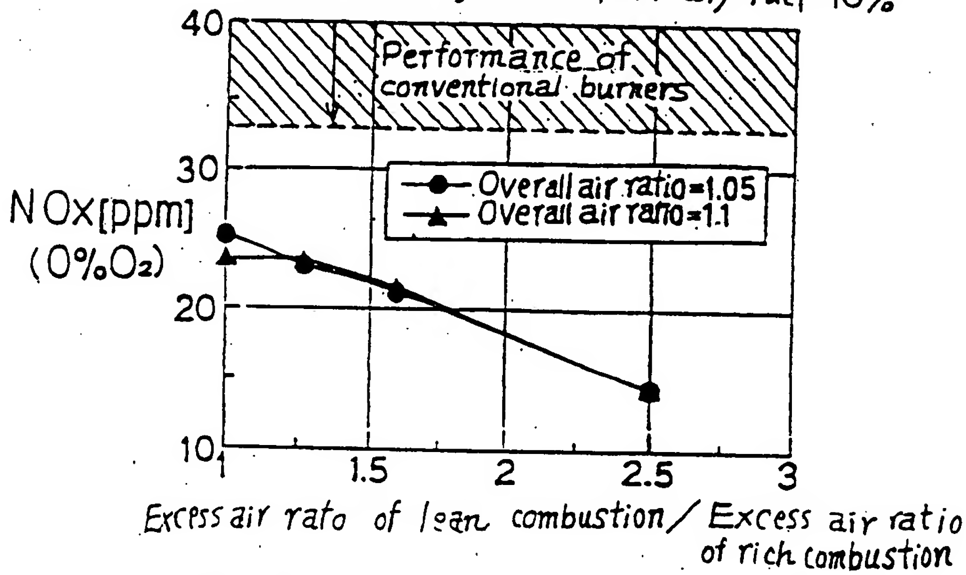


FIG.35

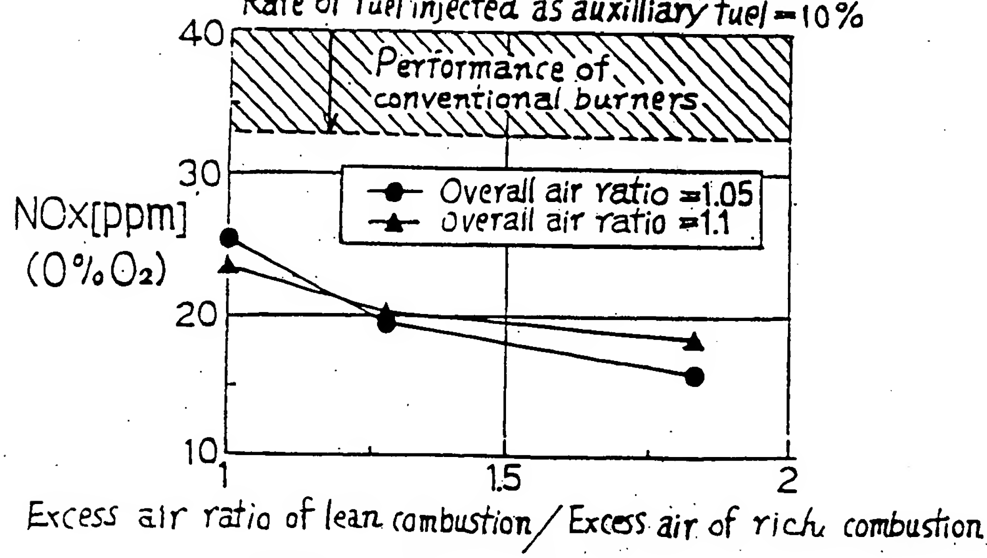
Combustion rate $=45\times10^4$[kcal/h]
Flow velocity ratio (air/fuel) = 0.3
Area of the air injecting portion for forming annular air flow = 0.16
Rate of fuel injected as auxiliary fuel = 10%



(Using the slot-like air injecting portions different in area)

FIG.36

Combustion rate $=45\times10^4$[kcal/h]
Flow velocity ratio (air/fuel) = 0.3
Area of the air injecting portion for forming annular air flow = 0.16
Rate of fuel injected as auxilliary fuel = 10%



(Using the base fuel injecting portions different in area)